Radiographic Atlas of
Skeletal Development of the Foot and Ankle

Radiographic Atlas of Skeletal Development of the Foot and Ankle

A STANDARD OF REFERENCE

By

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CHARLES C THOMAS • PUBLISHER
Springfield • Illinois • U.S.A.

CHARLES C THOMAS • PUBLISHER
BANNERSTONE HOUSE
301-327 East Lawrence Avenue, Springfield, Illinois, U.S.A.

Library of Congress Catalog Card Number: 61-51373

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Preface

PREPARATION OF THIS ATLAS was interrupted during 1958 by the illness and death of Normand L. Hoerr, who was directing its composition. Since then, S. Idell Pyle and Carl C Francis have brought the volume to completion, making every effort to finish the book in accordance with the desires and ideals of Doctor Hoerr. They have deemed it desirable to add some recent material which had not been available in published form to Doctor Hoerr. However, they have included nothing which in their opinion is alien to his original plan for the book.

Doctor Hoerr was convinced of the fundamental value of this atlas. It was a great disappointment to him not to be able to see its publication. The Department of Anatomy, Western Reserve University, is honored to present this book as a tribute to his memory.

SAMUEL W. CHASE

Foreword

THE DESIGNING OF THIS ATLAS was begun in 1928 by the late T. Wingate Todd, first Henry Willson Payne Professor of Anatomy of Western Reserve University, Cleveland, Ohio. It was essentially completed in 1958 by his successor, the late Normand L. Hoerr. The continued simplicity and clarity of the design have been a unique stimulus for all who have worked with them during its preparation.

The major section in the atlas is the standard of reference. It consists of a set of radiographs depicting the maturation of the foot and ankle. The set has been spaced chronologically so that the developmental level of a child's foot and ankle can be assessed from a single film.

Dr. Todd began the designing by selecting a standard film continuum for boys and girls, respectively, or a two-part standard. At the time of his sudden death in 1938, he had assembled slightly more than one-half the number of films of the foot as are available in the Brush Foundation collection. He had not completed a text for his atlas although the standard had been prepared and issued to a number of laboratories in the United States and abroad. The assembling of materials and the testing of the standard were continued under the direction of William Walter Greulich, Dr. Todd's successor as Director of the Brush Foundation Studies, until he assumed his present post as Professor of Anatomy in Stanford University, Stanford, California. Dr. Hoerr then continued the administrative role of bringing the atlases to their completion. By 1947 an entirely new two-part standard for the foot and the necessary plate descriptions had been assembled from the completed Brush Foundation film collection.

In addition to his personal research interests, his administrative roles in scientific organizations locally and internationally, and his work with many facets of medical education, Dr. Hoerr found time to examine the current clinical and teaching values of Dr. Todd's unpublished atlases and to direct their point of view accordingly. He was convinced that a single standard of reference, for the male and female, was the next formulation to be developed from film collections in three cooperating institutions and Dr. Todd's original work. Accordingly, between 1950 and 1955, he directed and participated in the preparation of a single standard of reference for the knee as the first of such a series.

The link between a two-part standard of reference and a single standard derived from it is the series of transitional morphological markings and processes which appear on the radiographic silhouettes of bones during the osseous stage of their development. These markings are known as skeletal maturity indicators; they are neither sex-limited, race-limited, nor generation-limited.

It proved to be relatively easy to prepare the single standard of reference for a region of the body containing only a few bones, such as the knee. Dr. Hoerr decided that a similar standard should be attempted for what is perhaps the most complex region of the skeleton, the foot and ankle. Between 1955 and 1957, he drafted a text for the foot atlas and participated in the choice of all standard plates. Those readers who have known him will readily understand why the task of polishing his text after his death in December 1958 has been brief, instructive, and most rewarding. We hope we have presented the formulation, data, and the many accumulated notes available to us accurately and clearly.

This atlas has been finished as it was begun, namely, for "The Children of America and of the World . . . to the end that physical and mental health, in their fulness, may be added to the ideals of Loyalty, Honor and Service."[1]

S. Idell Pyle

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Radiographic Atlas of
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I Introduction

THIS ATLAS is the third of a series of standards—Greulich and Pyle, 1950, second edition, 1959;[2] Pyle and Hoerr, 1955[3]—based upon the completed collections of the Brush Foundation studies of human growth and development, which were initiated and prosecuted in this laboratory under the direction of the late T. Wingate Todd. The film series, from which the standard plates depicting successive stages of maturation of bones of the foot and ankle were selected, constitute a portion of the developmental histories of 4483 Cleveland children from approximately 2600 families and 134 Boston children from more than 100 families.

Originally six series of x-ray films were accumulated and provisional standards were prepared by Dr. Todd and his associates between 1932 and 1936: hand, elbow, shoulder, hip, knee and foot. Dr. Todd was able to complete for publication only one atlas, *Atlas of Skeletal Maturation (Hand)*,[1] before his sudden death in 1938. Additional films were collected during continuation of the studies of development until the end of 1942, with the result that the completed records contain nearly twice as many films as were available to Dr. Todd.

The films which constituted the six standards of reference selected for the atlases originally planned by Todd were copied as contact-size transparencies and issued to a limited number of investigators in the United States and abroad. These transparencies of his standards should not be confused with the plates in the first editions of the Greulich and Pyle hand standard, the Pyle and Hoerr knee standard, and the provisional standards for foot by Hoerr and Pyle on which this atlas is based. Todd's original work is now included as a part of the Brush Inquiry collection in the School of Medicine of Western Reserve University of Cleveland, Ohio. Because publications of a number of investigators have been based upon both sets of the standards of reference mentioned above, especial mention is made here of the status of the foot atlas which Todd was preparing as the second volume of his projected series [1] at his sudden and untimely death. He had not completed the text of his foot atlas, but he had selected those contours of individual bones which he used as "maturity determinators" for the region. These maturity determinators were similar to those for the hand and wrist in his published atlas. In the current series of atlases we use the term "maturity indicator" with essentially the same meaning as the term originally proposed by Dr. Todd. By maturity indicator we mean an osseous feature in the contour of a developing bone which can be used as a reliable maturational landmark in the sequence of ossification of the bone. The sequence of characteristic developmental features as seen in radiographs is not altered appreciably by race or sex.

Skeletal maturity indicators of any bone can best be selected from consecutive film series and validated by single radiographs of children of the same chronological age in a study group. The time intervals between maturity indicators of a series can be determined more precisely by relying upon consecutive films of individual children. We are indebted to Dr. Harold C. Stuart, director of Longitudinal Studies of Child Health and Development at the Harvard School of Public Health, for his generosity in making available his eighteen year film series of 134 children for use in completing the standardization of the age equivalents for the skeletal maturity indicator series presented in this atlas. Plates 2, 5, 8, 9, 11, 13 and 18 of Part II of the atlas and the maturity

indicator series for the distal ends of the tibia and fibula in Part III are from films in Dr. Stuart's collection. We selected them as substitutes for their counterparts in our original set of plates chiefly because they provide better views of individual bones at some stages of ossification.

The introductions in the previously mentioned atlases,[1, 2, 3] contain accounts of the families, community agencies and national foundations to whom the School of Medicine of Western Reserve University is indebted for the Brush Inquiry collections of developmental histories. The authors are particularly indebted to the Nutrition Foundation, Inc. for successive grants-in-aid which have made it possible to bring this third atlas to completion. The standard plates, like those of the hand atlas and the knee atlas, were produced by David G. Shields, photographer in the Division for Babies and Children, University Hospitals, Western Reserve University. The drawings have been made by William H. Golden of the Bolton Study, Department of Anatomy, School of Medicine. Robert A. Whitmore, our roentgenographic associate from 1939 to 1944, provided continuity in the film series. It is a pleasure to acknowledge not only their careful workmanship but their cooperativeness at all times.

Especial mention must be made of the assessments of onset of ossification in the epiphyses and tarsal bones of the foot made by Ida Lieb Slutsker and Clara Buehl Whittaker. It is a pleasure to acknowledge their excellent work and their initiative in preparing the material included in a number of the tables. Much of their work was carried out with the collaboration of one of us (S.I.P.). Plate I is from the private collection of films of newborn infants made by one of us (S.I.P.). The Brush Foundation histories contain no films of children at birth. We are similarly indebted to Dr. Icie G. Macy, of the Merrill-Palmer Institute of Human Development and Family Life of Detroit, Michigan, for permitting us to use her film collection to validate our maturity indicator series in Parts II and III.

We cannot adequately express our indebtedness to Dr. Carl C Francis, Associate Professor of Anatomy of this Department who originally worked with Dr. Todd, for checking our standard plates and rough draft descriptions. This direct association which we have had with the original Todd work has been invaluable throughout the preparation of this atlas.

Under Dr. Todd's direction, the first series of maturity indicators of foot bones were assembled by the coauthor of this atlas, Dr. S. Idell Pyle. She also initiated the recent work here on maturity indicator series of joints of the body. In view of the greatly augmented film collection and her more recent work on maturity indicators for joints as well as for individual bones, the Todd foot atlas has been left in its unfinished state. This atlas is now on file with the Brush Inquiry records in the School of Medicine, Department of Anatomy, Western Reserve University.

We have been asked why six atlases were planned originally for the Western Reserve University series, and the answer is twofold. All bone growth centers do not reach the osseous stage of their development simultaneously, and anatomists and clinicians have need for a reference standard which demonstrates the time span of the osseous stage in growth centers, bone by bone. The six regional atlases seem to provide logical bone groupings; of necessity they must resemble each other closely in design as well as rate in order to be used interchangeably as expressions of the developmental level of a child's bodily framework.

It has been sufficiently proved that some bone growth centers in each region vary more widely in their times of onset of ossification in children than other centers which subtend the same muscles and ligaments. The sequences of onset of ossification in the centers are quite different from the completion-sequences both in the skeleton as a whole and in the six regions.[37] Variations of the shape of regularly occurring bones of the adult skeleton are said to occur most frequently in the foot, yet it was possible to select maturity indicator series for each bone of the region. We have also studied the development of the accessory bones and the variant nodules in the middle and distal phalanges. The accessory bones displayed the individualized schedules of develop-

ment of the growing feet in which they were found. Thus a clear distinction should be made between variability in times of appearance of a maturity indicator in children and diversified forms of the indicator whenever the term "osseous variability" is used in conjunction with this standard of reference.

As we repeatedly studied ways of relating the developmental levels of the six parts of the skeletal system, we have examined in detail those maturity indicators of long, short and irregular bones which are identical in kind. The spans of the intervals between first appearance of two indicators in some bones are nearly identical, but for more than half of the bone growth centers of the extremities these spans differ by a few months to several years in every population of children. The ultimate impact of a present change in a child's health status upon growth of its bone can be gauged in part by application of these chronological age differences. The principle, expressed for adult bone by Norman W. Ingalls of this laboratory,[4] that ontogenetic and phylogenetic influences give similar evidence of their attributes in teratological, pathological and normal bone conditions has proved to be a workable assumption for preadult atlases from the beginning of the Brush Foundation studies. The evidence consists of emerging joint forms. Comparisons of Figures 3 and 4 of the knee atlas[3] with the descriptions of individual maturity indicators of the hand and wrist[2] and of the foot and ankle in Part III of this atlas may aid the reader in his search for identical maturity indicators throughout the skeletal system.

In 1944, as we were beginning to prepare this atlas, Frederic Wood Jones published his monograph *Structure and Function as seen in the Foot.*[5] Perhaps the following quotation from his introduction will encourage others, as it did us, to study the many excellent textbooks and articles on the human foot from new points of view but to be cautious in assuming that swift changes in natural bone form might be found if one were to compare the feet of two generations of children.

> Man's foot is all his own. It is unlike any other foot. It is the most distinctly human part of his anatomical make-up. It is a human specialization and whether he be proud of it or not, it is his hallmark and so long as Man has been Man and so long as he remains Man it is by his feet that he will be known from all other members of the animal kingdom. He may speak slightingly of feet of clay and imagine his form to be divine with perhaps the exception of his feet, but with all his conceit he must not ever forget that it is, in fact, his feet that confer on him his only real distinction and provide his only valid claim to human status. We may, therefore, assume that we have every guarantee that the foot is a proper subject for examination for its own sake.

Thus we hope we have described some osseous features in the following pages which may serve as references to indicate the developmental level of a child's foot according to its radiograph without minimizing the prime values of recognizing individual variation of bone form in groups of children.

N. L. H.
S. I. P.

PART I

II Development of the Foot and Ankle; Selected Studies

While the Western Reserve University studies of normal bone growth have been progressing, numerous comprehensive studies of the structure, dimensions, and key surgical landmarks of the human foot and ankle have been published by other investigators. The studies which provide basic information for the formulation in this atlas have been those based on anatomical and surgical sections, anthropometry, footprints, and radiographs. Several pages would be needed to merely list the reports which have provided a rich background for our radiographic interpretations of the transformation of cartilage (bone) into hard bone. The papers of Hallisy,[6] Willis,[7] and Ingalls[8, 9] on the adult foot from this Department of Anatomy, Hill's anatomic and radiographic study of fetuses[10] and those of Straus[11] and Senior,[12] and two papers on onset of ossification by Francis and others,[13, 14] became available concurrently with the Todd atlas.[1] O'Rahilly, Gray and Gardner have recently made comprehensive additional studies of fetuses, among them a comparison of the development of the fetal hand and foot,[15] which should be studied in detail.

The reader who wishes to familiarize himself with present information on growth and differentiation of skeletal tissues and joints is referred to Ham's *Histology*[16] for his clear and detailed account and illustrations. The recent article by Anderson, Blais and Green,[17] summarizing foot lengths of healthy children from age one to eighteen years as derived from precise anthropometric and radiographic records has added significantly to the data on foot size and proportions.

Accessory bones of the body are usually found most frequently in the lower extremity. Trolle's monograph[18] and O'Rahilly's paper[19] have brought us up-to-date on the historical findings and terminology for these structures. Caffey's textbook for radiologists[20] includes numerous clear illustrations of accessory bones and a discussion of variation of growing bones throughout the skeleton in contrast with the foot.

In the completed Brush Foundation records, there are many ten-year series of two radiographic views of the left foot, a lateral and a dorsoplantar view. Each child's series also contains two sets of footprints of both feet. One set was made while the child was seated, and the other set was made as it stood up. For the two radiographs, the child was placed supine on the x-ray table, the left leg was flexed so that the sole of the left foot was flat upon the film-holder, and the dorsoplantar radiograph was then made. For the lateral view film, the child turned to lie upon its left side with the outer border of its left foot upon the film-holder. The tube-to-target distance was thirty-six inches.

These ten year footprint series for the youngest group of children were started at the examination immediately after each child began to walk; at the twelve, the eighteen, or the twenty-four months examination. While Todd was organizing his foot study plan, King[21] published an evaluation of footprinting methods.

One of the solutions* which she had tried was used throughout the Brush Foundation study. For its footprint in the nonweight-bearing position, the child sat upon the bench which had been used during measurement of its sitting height. Two pieces of Bristol board were used for the footprint records. The examiner brushed the printing solution upon a metal plate, and showed the child how to coat the soles of its feet

* 55 cc. tincture of iron chloride, 45 cc. of medicated alcohol, and 10 cc. of glycerin.[21]

sufficiently by rubbing them over the solution plate. The feet were then raised enough to substitute a Bristol board for the solution plate, the feet were positioned on the Bristol board and the footprints were thus recorded. The coating procedure was repeated, the second Bristol board was positioned, and the child stood upright upon it. The examiner either had offered the child both hands to assist it while rising or had suggested that the child place its hands upon the examiner's shoulders.

Thus in this growth clinic, it became routine practice to record both size of body parts and presence of human maturity indicators. Developmental level is frequently masked by size. Without reference to the chronological age of the child, these data are obviously incomplete. This was the premise which Todd followed in selecting the elements of his maturity indicator scales. Hill[10] completed one of the first summaries in Todd's laboratory in which fetal size and osseous developmental level were compared "to extend into fetal life the principles of maturity assessment devised for postnatal life by Dr. Wingate Todd and elaborated by him in the Atlas of Skeletal Maturation (Hand)."

Hill studied 500 stillborn fetuses. He reported recognizable differences in the maturity of male and female fetuses by the seventh fetal month, with female fetuses the more advanced. From the onset-of-ossification sequence throughout the body, he made a developmental timetable for the fetal stage. He remarked that his timetable would probably show more variability than one constructed from records of viable fetuses, such as that of Menees and Holly[22] which was based upon films of 643 infants who survived the newborn stage. Working simultaneously with Hill and using 534 radiographs of Brush Foundation children, Francis, Werle and Behm[13] linked Hill's fetal bone differentiation timetable with onset of ossification in the remainder of the regularly occurring bone growth centers of the upper and lower extremities. The Appendix of this atlas contains the recent extension of the studies of Francis, Werle and Behm by Slutsker and Whittaker using the completed Brush Foundation film series.

Such onset-of-ossification sequences have long tempted investigators to use them, so far as they can be extended chronologically, as sufficient evidence of progress of ossification throughout the skeleton. Investigators remind us that these data show "bones are variable." Wherein is the *process* of a skeletal region's ossification variable? We shall attempt to provide some of the answers to this logical question in subsequent sections of this atlas.

Senior[12] had found that the sequence of chondrification of the elements of the foot is precise, a sequence which was verified in 1957 by O'Rahilly, Gray and Gardner[15] by means of serial sections of 103 human embryos. The embryonic tissue masses from which bones of the foot and ankle develop were beginning to chondrify between the fifth and seventh ovulation weeks, and the sequence most frequently observed was as follows:

	Round or irregular bones	*Short bones*
1.		Metatarsals II, III, IV
2.	Cuboid	Metatarsal V
3.	Calcaneus, talus, lateral cuneiform	
4.	Intermediate cuneiform	
5.	Medial cuneiform	Metatarsal I
6.	Navicular	
7.		Proximal phalanges II, III, IV
8.		Proximal phalanx V
9.		Proximal phalanx I
10.		Middle phalanges II, III, IV
11.		Middle phalanx V
12.		Distal phalanx I
13.		Distal phalanx III, IV
14.		Distal phalanx V

The chondrification sequence obviously refers to the entire bone including diaphysis and epiphysis of short bones. The timetables of Francis, Werle and Behm[13] are largely for epiphyseal bone. This should be noted when sequence of chondrification and sequence of ossification are compared. Thus compared, the sequence of chondrification differs from the sequence of ossification. In order to test their assumption further, we studied this chondrification sequence according to anatomical forms of bones and the recently summarized ossification sequence shown by the onset-of-ossification tables and the long-term series of individual children. An interesting

Figure 1. Ossification sequence in the foot. In the upper part of the figure are shown films of the left foot of three fetuses. From left to right the approximate ages of gestation were four, five and six and one-half months.

In the lower part of the figure the lateral view of the left foot illustrates the three subdivisions; hindfoot, midfoot and forefoot. In the hindfoot are included the lower ends of tibia and fibula, talus and calcaneus. Under midfoot are included the remaining tarsal bones. The forefoot is composed of metatarsals and phalanges. See Plate 16 for the dorsoplantar view.

Figure 2. Lateral radiographs and accompanying footprints of a girl from the Research Series whose films repeatedly appeared in the modal group of 100 films. At age two years her feet were beginning to show arches; at ten years the arches were high.

Figure 3. Lateral radiographs and accompanying footprints of a girl from the Research Series at age two years, four years and six months and ten years, whose films repeatedly appeared beyond the sixty-sixth position in the array of 100 films. At age two years her arches were already more developed than those of the girl in Figure 2.

similarity is seen when the bones are grouped according to tarsals, metatarsals, and phalanges, respectively. The cuboid, or "keystone" tarsal, and the distal phalanx of the great toe are two noteworthy exceptions.

Left-foot radiographs of three fetuses are shown in Figure 1 as examples of fairly typical prenatal onset-of-ossification order throughout the region. Reading from left to right, the proximate ages are: four, five, and six and one-half months according to the lengths of gestation. The oldest infant grew up, the other two survived briefly. All three mothers appeared in good health prior to the sudden termination of their pregnancy. The figure shows that ossification begins latest in the midfoot. Also in Figure 1, a lateral-view film of the foot of a Research Series boy has been reproduced to illustrate our grouping of foot bones according to hindfoot, midfoot, and forefoot.

Our recent work on radiographic skeletal maturity indicators of joints has been previously mentioned in the Introduction. The indicator series in our six atlases have been based, of necessity, upon those indicators of bones which they continue to possess in common after their initial indicator, onset of ossification, has disappeared. We refer to them now as the "cardinal maturity indicators" of each bone's series. We became aware of their especial usefulness while we were tracing appositional development of joint surfaces. Our first example was given in Figures 3 and 4 of the knee atlas.[3]

A joint and a joint cavity each displays radiographically-paired markings (morphologic attributes) of two bones. The number of indicators necessary for quite precise identification of symmetry of ossification of a region may be reduced by approximately one-half between early childhood and adolescence, if the cardinal maturity indicator formulation is used. The embryologist's use of the term "horizons" serves to alert us to time spans between cardinal maturity indicators. Formation of joint cavities has been reported as well under way throughout the feet of three and four month old fetuses. The ossification of foot bones is completed late in adolescence. Thus the time span of joint formation in the foot and ankle of the female and male, respectively, is fifteen and seventeen years whenever the rate of growth has been a moderate rate.

In 1944, Meredith[23] reviewed many data of foot lengths of North and Central Americans. He independently confirmed Hill's observation that a slight difference between the developmental levels of the male and female foot exists at birth. The initial external indicator of regional differentiation is the appearance of the ankle crease. Subdivision of the region into "foot" and "ankle" then follows with a paddle-shaped segment, no toes visible. The heel soon forms, and five discrete toes appear.

We have stated previously that postnatal development of the foot and ankle had been recorded for the Brush Foundation children by means of two radiographs and two footprints. Tables I and II and Figures 2 and 3 have been assembled as examples of some relationships of foot size and its skeletal differentiation.

Our ten-year footprint series gave many examples of a variety of foot lengths and footprint shapes. These footprints may be less precise records of size of feet than anthropometric measurements due to the spreading of the solution while it dried. Table I has been abstracted from the Tables of Anderson, Blais and Green.[17] Table II contains our own measurements of foot length from the weight-bearing footprints of eight Research Series children; their radiographs, in the ranks of 100 ten year old children, showed that their feet were in significantly different stages of skeletal development at that age.

Meredith[23] has stated that at birth the male foot has attained 34 per cent of its adult length. By age three years, according to the measurements of Anderson, Blais and Green[17] the feet of both boys and girls will be slightly more than two-thirds as long as they will become by age ten. By age fifteen years, the male foot has attained about 98 per cent of its adult length, while by ages twelve to thirteen years the female foot is within 98 per cent as long as it will become. Reference to our standard in this atlas will show that these chronological ages, twelve to thirteen years, and fifteen years, respectively, mark quite

TABLE I

LENGTH OF NORMAL WEIGHT-BEARING FOOT IN CENTIMETERS. PER CENT OF 13 YEAR OR 15 YEAR LENGTH. PROPORTIONS OF CALCIFIED OS CALCIS, "HEEL," CUBOID, AND METATARSUS EXPRESSED AS PER CENT OF TOTAL FOOT LENGTH WHEN MEASURED FROM LATERAL ROENTGENOGRAPHS. 1-18 YEARS. ADAPTED FROM ANDERSON, BLAIS AND GREEN ([17])

Age	*No. of Boys*	*Foot Length*	*% of 15 Yr. Length*	*No. of Boys*	*Calcified Os Calcis*	*"Heel"*	*Cuboid*	*Metatarsus*
1	17	11.90	46.2	10	21.5	32.2	13.9	15.3
2	40	13.50	52.5	10	23.9	33.1	14.3	16.1
3	61	15.07	58.6	10	25.2	33.4	14.2	15.5
4	84	16.29	63.4	10	26.4	33.7	14.2	15.9
5	80	17.27	67.2	10	27.1	34.0	14.3	15.8
6	78	18.19	70.8	10	27.2	33.6	14.2	16.0
7	76	19.23	74.8	10	27.3	33.3	14.1	16.0
8	92	20.16	78.4	10	27.4	33.1	14.0	15.8
9	83	21.08	82.0	10	27.8	33.0	13.7	15.6
10	98	21.89	85.1	10	28.2	33.1	13.5	15.4
11	112	22.58	87.8	10	28.5	33.2	13.3	15.3
12	126	23.51	91.4	10	28.9	33.2	13.1	15.2
13	138	24.22	94.2	10	29.3	33.3	12.9	15.3
14	152	25.06	97.4	10	29.7	33.7	12.7	15.6
15	147	25.71	100.0	10	30.1	33.8	12.5	16.3
16	139	26.04	101.3	10	30.1	33.5	12.5	16.6
17	128	26.11	101.6	10	30.3	33.4	12.5	16.6
18	107	26.14	101.7	10	30.2	33.4	12.5	16.6

Age	*No. of Girls*	*Foot Length*	*% of 13 Yr. Length*	*No. of Girls*	*Calcified Os Calcis*	*"Heel"*	*Cuboid*	*Metatarsus*
1	21	11.87	50.4	10	22.6	32.1	13.7	16.5
2	30	13.47	57.1	10	24.3	32.7	14.0	16.7
3	42	14.86	63.0	10	25.4	32.6	13.8	16.3
4	66	15.93	67.6	10	26.0	32.6	13.8	16.3
5	64	17.07	72.4	10	26.1	32.4	13.6	17.0
6	64	18.25	77.4	10	26.3	32.3	13.6	16.9
7	69	19.13	81.2	10	26.6	32.2	13.6	16.7
8	74	19.91	84.5	10	27.3	32.4	13.4	16.6
9	86	20.86	88.5	10	27.6	32.3	13.1	16.6
10	94	21.65	91.9	10	28.2	32.4	13.0	16.8
11	105	22.44	95.2	10	28.5	32.3	12.4	16.8
12	110	23.15	98.2	10	28.6	32.5	12.3	17.1
13	113	23.57	100.0	10	28.7	32.6	12.1	17.0
14	106	23.77	100.8	10	28.9	32.6	12.1	17.2
15	98	23.84	101.1	10	28.9	32.7	12.1	17.2
16	88	23.82	101.1	10	29.0	32.8	12.1	17.2
17	80	23.84	101.1	10	28.9	32.8	12.1	17.2
18	60	23.87	101.3	10	28.9	32.8	12.1	17.2

FOOT LENGTH: From tip of great toe to back of heel, weight-bearing position. CALCIFIED OS CALCIS: its horizontal diameter. "HEEL:" from skin at back of heel to mid-point between os calcis and cuboid. CUBOID: mid-point between os calcis and cuboid, to mid-point between cuboid and fourth metatarsal. METATARSUS: mid-point between cuboid and fourth metatarsal, to distal epiphyseal line of fifth metatarsal.

accurately expected "epiphyseal-diaphyseal fusion age" for the female foot and the male foot if each has been developing on a moderate schedule.

Footprinting, with its known limitations, is a permanent graphic record. For the clinician it is quite significant that anthropometric (direct) measurements and size calculated from films or footprints are reasonably similar. The footprints of eight children, each developing according to a different rate,* all showed slightly less rapid differentiation between ages two and ten years than did the feet of Boston children. These differences were confirmed by the skeletal ages (foot) which, for example, were as follows for the four boys; 8.8, 9.9, 11.2, and 13.2 years. The skeletal ages (foot) of the four girls were analogous.

We have repeatedly found it enlightening to study differentiation of the foot in terms of hindfoot, midfoot, and forefoot bones, that is, differentiation in terms of (the only) long-bone epiphyses of the region and its two largest tarsals, the remaining tarsals, and the regularly

* For each sex, the least mature foot in the ranked arrays of 100 foot films at each age was assigned number 1 and the most mature foot was assigned number 100.

TABLE II

Per Cent Change in Foot Length Between Ages Two and Ten Years According to Direct Measurements and Lengths of Footprints. Average Annual Change For Boston Children and Change at Regular Intervals For Eight Cleveland Children Who Were on Different Skeletal Developmental Levels at Age Ten Years

Age in Years:	*7th Boy:*	*31st Boy:*	*68th Boy:*	*100th Boy:*	*Boston Boys:*
		Foot length ratios, according to footprint series: four Cleveland boys			*direct measurements*
2	62.4	60.3	57.0	—	61.7
2½	64.4	65.2	63.6	—	—
3	—	67.4	66.8	69.1	68.8
3½	68.0	70.5	70.1	—	—
4	71.6	73.2	69.2	72.4	74.4
4½	72.7	74.6	73.8	74.8	—
5	76.3	77.2	76.6	77.6	78.9
6	80.4	83.0	—	83.2	83.1
7	86.1	87.0	86.0	86.4	87.8
8	91.2	90.6	91.1	91.6	92.1
9	93.8	94.1	93.9	95.8	96.3
10	100.0	100.0	100.0	100.0	100.0
Print length at 10 years:	19.4 cm.	22.4 cm.	21.4 cm.	21.4 cm.	Average foot length at 10 years – 21.9 cm.
Boy's weight:	63.5 lbs.	76.8 lbs.	96.5 lbs.	98.0 lbs.	
Boy's height:	133.0 cm.	145.2 cm.	146.1 cm.	147.6 cm.	

Age in Years:	*6th Girl:*	*31st Girl:*	*68th Girl:*	*98th Girl:*	*Boston Girls:*
		Foot length ratios, according to footprint series: four Cleveland girls			*direct measurements*
2	—	61.0	57.9	58.7	62.2
2½	—	62.6	63.8	60.0	—
3	66.3	65.6	66.5	63.1	68.6
3½	68.9	68.2	70.6	68.9	—
4	72.4	73.8	74.2	70.7	73.6
4½	75.0	74.9	76.0	73.8	—
5	76.0	77.4	76.9	74.5	78.8
6	81.1	82.6	84.6	82.2	84.3
7	86.7	86.7	86.4	87.1	88.4
8	89.8	90.3	90.5	91.1	92.0
9	95.4	93.8	95.0	93.3	96.4
10	100.0	100.0	100.0	100.0	100.0
Print length at 10 years:	19.6 cm.	19.5 cm.	22.1 cm.	22.5 cm.	Average foot length at 10 years – 21.6 cm.
Girl's weight:	61.2 lbs.	66.8 lbs.	122.8 lbs.	56.2 lbs.	
Girl's height:	135.8 cm.	152.5 cm.	152.5 cm.	142.6 cm.	

The least mature foot in the ranked arrays of 100 films at each age was assigned number 1 and the most mature foot was assigned number 100.

occurring short bones. The tripartite subdivision has become increasingly useful as our study of intermediate maturity indicators of joints has progressed. Anderson, Blais and Green [17] have made similar subdivision of the region. Consequently their conclusion, as follows, has been of particular interest to us:

"For practical purposes, the proportions of the foot as measured from landmarks (see their Table IV) chosen on these roentgenograms may be said to be stable throughout the years of growth, individual variation being a stronger factor than changes in proportion which occur with age. The relative amounts of total foot length contributed by the mid-tarsal segment, by the metatarsal segment as well as by the heel, were very similar throughout the growing years."

III Anatomic and Radiographic Terms

In the atlas on the development of the knee we explained the method of determining maturity indicators in the developing bones of children. After identifying on the radiograph the characteristic shadow of known markings of the adult foot, some of which have been named and others not, we traced back the earliest foreshadowing of the development of a protuberance, sulcus or other characteristic marking of an individual bone.

We have not hesitated to use an anatomical term for a part of a bone as soon as it is foreshadowed in the radiograph. Thus we can speak of the head and neck and trochlea of the talus or of a tubercle or of the sustentaculum tali of the calcaneus as soon as the characteristic marking which foreshadows the eventual position and contour of these parts can be seen in the films. For a considerable number of years, while bones are growing, their osseous portions have rudimentary facets and tuberosities: these are as identically positioned on each cartilaginous bone as are their counterparts on the fully developed bone. No confusion should arise through the use of the same terminology for the silhouette of a rudimentary process or marking in a film as for the counterpart of this marking in the adult bone. These markings are called intermediate maturity indicators.

In addition to this early use of recognized anatomical terms, we have introduced some terms for facets, processes and radiographic subdivisions of bones where recognized anatomical terms are lacking. We list below the definitions of some of these terms as we use them.

The foot and ankle contain three forms of bones which have frequently been called long bones, short bones and irregular or round bones. In general, long bones have a secondary center of ossification at each end. A short bone typically has only one epiphysis or secondary center of ossification. Usually irregular bones have no epiphyses.

The foot contains three exceptions to this general rule. The calcaneus and talus have been classified as irregular bones. However, the calcaneus has at least one regularly occurring epiphysis. The os trigonum is a small epiphyseal-like portion of the talus and stems from a quite regularly occurring growth center. The third exception is the fifth metatarsal listed as a short bone, with one epiphysis at its distal end. The os Vesalianum develops like an epiphysis on the proximal end of this metatarsal quite regularly in addition to the epiphysis on the distal end.

The shafts or diaphyses of the metatarsals and of the phalanges typically begin to ossify in the third or fourth month of gestation. The calcaneus and talus begin to ossify in the fourth to sixth fetal month. These centers, therefore, have been present in all the newborn and premature children we have seen.

Diaphysis: By diaphysis, as in the use of all terms for parts of bones, we refer only to the ossified portions of bones visible in the radiograph. The diaphysis, therefore, is the ossified portion of the shaft of a long or short bone; the epiphyses are excluded.

Metaphysis: The newly formed bone at the end of the diaphysis underneath the growth cartilage plate.

Growth Cartilage Plate or Strip of Lesser Density: The radiolucent ribbon or blank space within the long or short bone, respectively, between the epiphysis and metaphysis. This is sometimes called the epiphyseal line.

We use the terms strip of lesser density and growth cartilage plate interchangeably as soon

as the terminal plate of the epiphysis begins to be visible in the film. The contours of an individual growth cartilage plate or disc are established early and then are shown centrally until the epiphysis and metaphysis become equal in transverse diameter.

Epiphysis: The portion of the end of a long or short bone which will contain a secondary center of ossification.

Inner Bone Margin: The margin of the epiphysis which is attached to the growth cartilage plate and is separated in the radiograph from the metaphysis by the strip of lesser density.

Epiphyseal Terminal Plate: The white line outlining the inner margin of the epiphyseal center of ossification.

Outer Bone Margin: The entire circumference of the epiphysis excluding the inner bone margin. We use this term also for the outline of the nonepiphyseal end of a short bone including its articular facet, when it appears, and the sides of the joint margin. We also use the term for the entire circumference of an irregular bone.

Peripheral Growth Cartilage: A short bone typically ossifies from a single center of ossification in the center of the cartilaginous model of the bone. An irregular or round bone differentiates in a manner histologically similar to the calcification and ossification of a growth cartilage plate at the epiphyseal end of a long or short bone. Since any articular surface of a bone remains covered with a thin layer of hyaline articular cartilage in the adult, all the rest of a cartilaginous model of an irregular bone can be considered as peripheral growth cartilage.

Facet: A smooth, either flat or curved, initially thinly-outlined portion of the outer bone margin which is the forerunner of a joint surface.

Bone Growth Center: An ossification site in a bone, used interchangeably in this atlas with the term ossification center.

The initial nodules in the larger epiphyses of the body, that is, in long bones, are apt to be somewhat larger than those in the smaller epiphyses of the short bones and in irregular bones. Speed of organization of the initial deposit is not strictly proportional to the adult size of the bone. Any nonarticular portion of the outer bone margin is temporarily apt to be "thin" (that is, of low density) and even roughened, thereby lending itself to the impression of poor mineralization or vulnerability. Advanced and delayed nodules, respectively, of a region thus are apt to differ in roughness of outline in a single radiograph. Onset of ossification in joint-bearing growth centers takes place throughout childhood. (See tables in the Appendix.) The age when a bone growth center reaches the osseous stage has little relation to bone size or subsequent course of organization of the outer bone margin.

Skeletal maturity indicators for children presumably should be selected from regularly occurring growth centers. We have emphasized *onset-of-ossification* because it is the earliest radiologic evidence of the position of the growth centers in hindfoot, midfoot and forefoot. The osseous deposit usually occurs in the center of the growth center. If it can be accepted that the particles in the cuboid in Standard Plate 1, for example, were deposited in the center of this child's cuboid, the initial deposit shows the position of the "keystone" of the lateral longitudinal arch many months before it could be identified in any other way.

Onset of ossification determined radiographically is later than the actual onset of ossification histologically.

Skeletal Maturity Indicator Scales: A series of osseous features of a portion of the developing bone. They appear in irreversible sequence.

Radiographic Subdivisions of the Foot and Ankle: It is sometimes convenient to view the region as though it consists of three groups of bones. The groups are referred to as *hindfoot*, *midfoot* and *forefoot*. See Figure 1 in the chapter on Development of the Foot.

The hindfoot includes the lower ends of the tibia and fibula, the talus and the calcaneus. It is frequently divided anatomically into "ankle" and "heel." Thus the hindfoot includes the distal ends of the only long bones of the region plus the two tarsal bones which begin to calcify prenatally.

The midfoot includes the five remaining tarsal bones; cuboid, navicular, and the three cunei-

form bones. Thus it contains irregular bones exclusively.

The forefoot includes the metatarsals and phalanges, and the regularly occurring sesamoid bones of the great toe. Thus it predominantly contains short bones.

Cardinal Maturity Indicators: In all bone growth centers, some transitional osseous processes or features have the same anatomical function and sequence of appearance. We refer to these features as cardinal maturity indicators of bones and joints. For example, the initial maturity indicator of each series for the bone growth centers described in Part III of this atlas is the first osseous nodule. This nodule is the first cardinal maturity indicator of the center. In the Knee Atlas[8] we have described this nodule as the maturity indicator which marks the structural center of the knee joint, as well. Adjacent pairs of cardinal maturity indicators of joints may be used interchangeably in skeletal maturity indicator scales.

IV Assessment of the Developmental Level of a Bone Growth Center

In the chapter on *Anatomic and Radiographic Terms*, skeletal maturity indicator scales have been described as a series of osseous features of a portion of a developing bone. The portion of the bone, in which the features used in the assessment of the developmental level are found, is its bone growth center or centers. Because these features appear during the osseous stage of bone growth, the site of initial bone deposition has been called the ossification center. We shall use the terms growth center and ossification center interchangeably.

The initial maturity indicator of the center is the first tiny bone nodule as it appears before it shows definite shape. The age when the nodule has this appearance is indicated by the phrase "onset-of-ossification." The final maturity indicator of a long or short bone is the terminal line within the diaphysis. Its presence is referred to by the phrase "epiphyseal-diaphyseal fusion." The analagous final maturity indicator of a tarsal bone is one of its osseous processes, usually one of the osseous corners at the edge of an articular facet. The first and final indicators mark the span of the subadult stage of bone development.

We refer to all of those features which appear between the first and final indicators of a bone as its "intermediate maturity indicators." They include rudimentary osseous processes and articular facets which are forerunners of the fully modeled processes and facets in the adult bone.

The largest number of papers in the literature of osseous growth and developmental levels have pertained to onset of ossification in the irregular bones of the wrist and foot and the epiphyses of the short bones of hand and foot. The classical method used most frequently to denote onset of ossification in a growth center has been to record the age of the child when its films first show a bony nodule. Unless children are x-rayed at frequent and regular intervals, it usually happens that the time at which an osseous nodule is first seen in a film of a child is actually some months later than onset of ossification.

For example, according to Table III, if a group of boys is being x-rayed every six months, the navicular and the epiphysis of the proximal phalanx of the fifth toe may not appear in the films of many of the boys until the film taken at age thirty-six months. However, both of these osseous centers might have been detectable radiographically about five months earlier or at the age of thirty-one months. Of course no center of ossification would have been detectable in the film taken at thirty months. The expected age of onset of ossification of these two centers could be determined much more precisely if the boys were to be x-rayed at one month intervals. This, however, would not be desirable, and it is not necessary.

An alternate method of assessing the ages of onset of ossification of different bony centers was first suggested by Todd's method of assessing regional skeletal age and has been thoroughly developed since it was introduced by Pyle and Sontag.[24] This method, which has been designated the method of assessment by interpolation, is carried out as follows. Let us assume in the example just cited that the films of one of the boys show no hint of a center of ossification for navicular or for the epiphysis of the proximal phalanx of his fifth toe at thirty months but do show these centers in his films taken at thirty-six months. We know that these centers must have first appeared at some time between thirty

TABLE III

MEAN CHRONOLOGIC AGE AND ORDER OF ONSET OF OSSIFICATION IN HINDFOOT, MIDFOOT AND FOREFOOT. CHANGES WHEN NUMBER OF CHILDREN IS INCREASED

Ossification center	*Mean Age (Months)* *50 boys*	*182–235 boys*	*Mean Age (Months)* *50 girls*	*156–236 girls*
		Hindfoot		
Calcaneus, Body	before birth	*	before birth	*
Talus	before birth	*	before birth	*
Tibia, Distal epiphysis	3.9	4.4	3.4	4.0
Fibula, Distal epiphysis	12.5	12.6	9.3	9.0
Calcaneus, Epiphysis	89.6	90.3	63.7	68.3
		Midfoot		
Cuboid	0.5	*	0.4	*
Lateral cuneiform	4.4	*	3.8	*
Medial cuneiform	21.9	24.1	16.7	15.7
Intermediate cuneiform	28.4	29.3	21.3	20.0
Navicular	33.4	33.8	25.8	23.3
		Forefoot		
Toe I, Distal phal. epiphysis	16.8	15.5	10.6	9.4
Toe III, Prox. phal. epiphysis	19.5	18.1	12.2	11.5
Toe IV, Prox. phal. epiphysis	21.0	20.0	13.6	12.7
Toe II, Prox. phal. epiphysis	22.2	20.7	14.1	13.6
Metatarsal 1, Epiphysis	27.7	28.5	20.1	19.9
Toe I, Prox. phal. epiphysis	29.9	27.7	20.3	18.8
Toe V, Prox. phal. epiphysis	32.0	30.5	21.3	20.9
Metatarsal 2, Epiphysis	33.4	35.3	25.8	24.3
Metatarsal 3, Epiphysis	41.5	42.1	29.1	28.6
Metatarsal 4, Epiphysis	48.7	47.8	34.0	33.4
Toe IV, Distal phal. epiphysis	51.2	52.2	30.7	30.3
Toe III, Distal phal. epiphysis	53.5	53.7	43.8	34.0
Metatarsal 5, Epiphysis	53.6	53.6	38.6	38.9
Toe II, Distal phal. epiphysis	57.0	58.5	35.5	36.2

* The large group of children was x-rayed initially at age 3 months, the small group at birth. See the tables in the Appendix for the age-order of these ossification centers among the centers of the upper and lower extremities of children.

and thirty-six months and the age of onset-of-ossification is assigned accordingly.

Reference to standard tables in the Appendix shows that the standard deviation for the time of onset of ossification for the navicular can be 13.5 months, and for the proximal phalangeal epiphysis of the fifth toe, 7 months. Thus for those boys whose naviculars ossify shortly after thirty months, the assignment of thirty-six months as the time of onset of ossification of the navicular distorts the raw data for a group by nearly half a standard deviation for some naviculars. Onset ages for some epiphyses, similarly, might be incorrect as much as five-sevenths of a standard deviation. It is fairly easy to recognize onset of ossification and the rate of development of the early nodule, and thus to interpolate.

By studying a large population and by studying ranked arrays of radiographs, we may obtain some idea of the morphological changes immediately after onset of ossification in a tarsal bone or phalangeal epiphysis. The first deposit in some centers, for example, usually appears as multiple little bony nodules which rapidly coalesce to make a spherical or oval nodule. In the case of an epiphysis, this bony nodule soon assumes a greater transverse diameter parallel to the metaphysis. Through the experience gained in surveying a large group of radiographs, we may estimate the rate at which these processes of coalescence and change in shape of the early bony epiphysis or tarsal occur.

We may in the one case say with considerable accuracy that the coalescence of the separate particles of initial ossification has occurred only a month or two before the radiograph under study was made; or, in looking at a nodule which has already begun to acquire an oval shape and to have individual contours, that the earliest deposit of bone in the cartilage must have occurred soon

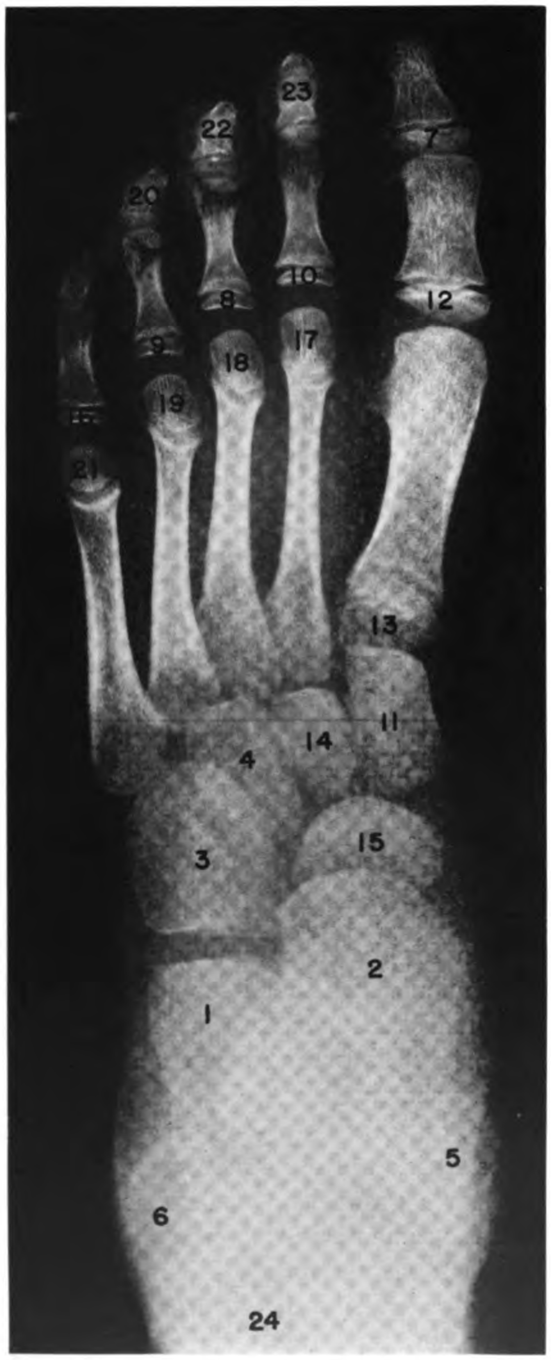
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Figure 4. Dorsoplantar radiograph of the foot showing the order of appearance of centers of ossification in the region as a whole. The numbers indicate the order of onset of ossification most frequently seen in boys.

1. Calcaneus, body
2. Talus
3. Cuboid
4. Lateral cuneiform
5. Tibia, Distal epiphysis
6. Fibula, Distal epiphysis
7. Toe I, Distal phal. epiphysis
8. Toe III, Prox. phal. epiphysis
9. Toe IV, Prox. phal. epiphysis
10. Toe II, Prox. phal. epiphysis
11. Medial cuneiform
12. Toe I, Prox. phal. epiphysis
13. Metatarsal 1, Epiphysis
14. Intermediate cuneiform
15. Navicular
16. Toe V, Prox. phal. epiphysis
17. Metatarsal 2, Epiphysis
18. Metatarsal 3, Epiphysis
19. Metatarsal 4, Epiphysis
20. Toe IV, Distal phal. epiphysis
21. Metatarsal 5, Epiphysis
22. Toe III, Distal phal. epiphysis
23. Toe II, Distal phal. epiphysis
24. Calcaneus, Epiphysis

TABLE IV

APPROXIMATE BOUNDARIES FOR EARLY AND LATE APPEARANCE OF THE INITIAL OSSEOUS NODULE IN THE BONE GROWTH CENTERS OF THE FOOT AND ANKLE. BOYS. AGES IN MONTHS

Bone growth centers grouped according to "sheaf" method of Francis, Werle and Behm (13)	*Francis-Werle average for 80th percentile bones (13)*	*Harding's 50% range (26)*	*Elgenmark's 50th per cent average (25)*	*Slutsker-Whittaker mean plus 1 S.D.*
	"early"	*"moderate rate"*		*"late"*
Cuboid	at birth	0.5– 1.5	2	*
Lateral cuneiform	2	2.5– 7	5.0	*
Tibia, Distal epiphysis	3	4 – 6	5.7	6
Fibula, Distal epiphysis	6	11 – 18	10.8	17
Toe I, Distal phal. epiphysis	11	13 – 18	14.0	21
Toe III, Prox. phal. epiphysis	13	15 – 23	20.8	23
Medial cuneiform	13	17 – 33	25.5	35
Toe IV, Prox. phal. epiphysis	14	16 – 24	21.8	25
Toe II, Prox. phal. epiphysis	14	16 – 27	21.9	26
Toe I, Prox. phal. epiphysis	20	25 – 34	28.8	33
Intermediate cuneiform	20	24 – 38	31.4	38
Navicular	21	25 – 58	38.1	48
Toe V, Prox. phal. epiphysis	21	24 – 36	28.8	37
Metatarsal 1, Epiphysis	22	23 – 34	31.9	34
Metatarsal 2, Epiphysis	26	29 – 32	39.0	42
Metatarsal 3, Epiphysis	35	37 – 49	39.5	50
Metatarsal 4, Epiphysis	39	42 – 58	47.5	56
Toe III, Distal phal. epiphysis	43	46 – 61	41.5	66
Toe IV, Distal phal. epiphysis	43	46 – 61	41.7	64
Metatarsal 5, Epiphysis	44	48 – 62	48.2	63
Toe II, Distal phal. epiphysis	44	50 – 68	39.5	61
Calcaneus, Epiphysis	74	87 –103	—	103

* Since Brush Foundation children were not filmed until age 3 months, the S.D. could not be properly derived for these centers.

after the previous film was made. In this way an assessment of thirty-two months or of thirty-four months is not too far from the exact age of onset which might be determined in a group of films taken at one month intervals.

The Tables of onset of ossification for centers throughout the body which we include in the Appendix of this atlas have been assembled from data obtained by the method of interpolation just explained. Means and standard deviations have been calculated to demonstrate the range of what we refer to as the onset age range for children growing at a moderate rate. Earlier studies in this laboratory by Francis[13, 14] also reported the ages of onset of ossification as found in Brush Foundation films. Francis used the classical method of assessment and then grouped his data into percentiles. He selected the eightieth percentile onset ages and grouped the ossification centers accordingly to prepare what has become known as his Sheaf Method chart.

It is remarkable how close to one another are the data of onset of ossification ages in the literature when they are expressed as means or fiftieth percentile norms. It would be expected that our average onset ages in the tables in the Appendix which have been assessed by the method of interpolation would be earlier than those assessed by the classical method. In both studies from this laboratory the children who were recovering from prolonged illness or had congenital defects were not included in the samples. In any sample of the population which includes previously sick children we would expect to find that the initial

TABLE V

Approximate Boundaries for Early and Late Appearance of the Initial Osseous Nodule in the Bone Growth Centers of the Foot and Ankle. Girls. Ages in Months

Bone growth centers grouped according to "sheaf" method of Francis, Werle and Behm (13)	*Francis-Werle average for 80th percentile bones (13)* "early"	*Harding's 50% range (26)* "moderate rate"	*Elgenmark's 50th per cent average (25)*	*Slutsker-Whittaker mean plus 1 S.D.* "late"
Cuboid	at birth	birth - 0.7	1.7	*
Lateral cuneiform	2	2 - 6	4.2	*
Tibia, Distal epiphysis	3	4 - 5	5.6	6
Fibula, Distal epiphysis	6	8 - 12	8.8	12
Toe I, Distal phal. epiphysis	7	7 - 11	10.2	12
Toe III, Prox. phal. epiphysis	8	10 - 14	12.3	15
Toe IV, Prox. phal. epiphysis	9	10 - 15	13.3	17
Medial cuneiform	9	16 - 25	20.6	23
Toe II, Prox. phal. epiphysis	10	11 - 17	14.9	18
Toe I, Prox. phal. epiphysis	14	15 - 22	19.6	24
Toe V, Prox. phal. epiphysis	14	15 - 26	21.0	24
Intermediate cuneiform	14	16 - 25	22.5	27
Navicular	14	17 - 31	25.9	34
Metatarsal 1, Epiphysis	14	16 - 22	20.0	24
Metatarsal 2, Epiphysis	19	20 - 30	25.9	29
Metatarsal 3, Epiphysis	22	25 - 34	29.1	34
Toe III, Distal phal. epiphysis	24	27 - 40	29.3	43
Toe IV, Distal phal. epiphysis	24	25 - 36	29.5	38
Toe II, Distal phal. epiphysis	26	29 - 43	29.1	45
Metatarsal 4, Epiphysis	26	28 - 39	32.0	41
Metatarsal 5, Epiphysis	29	33 - 45	35.0	48
Calcaneus, Epiphysis	54	56 - 71	—	74

* Since Brush Foundation children were not filmed until age 3 months, the S.D. could not be properly derived for these centers.

osseous nodules would appear later and would have a wider total range of onset ages among the children.

For example, let us compare the data summarized in Tables IV and V for three groups of children with fairly uniform health status with that of Elgenmark.[25] Elgenmark studied 2000 children from a hospital population, that is, he included children who had initially come to the hospital to be treated for some illness. He used the classical method of assessing onset of ossification and divided his data into quartiles. According to his data, for example, 50 per cent of the boys achieved onset of ossification in the cuboid at two months and 75 per cent at 3.7 months. These ages would classify these cuboids as on a somewhat delayed schedule according to our data. Slutsker and Whittaker found the nodule so well developed in the first radiographs of the Brush Foundation children taken at age three months that a true mean and standard deviation could not be calculated for this bone. Elgenmark listed the first appearance of the lateral cuneiform in the fiftieth percentile group as five months; this figure is in good agreement with Harding's data[26] for Boston children in Table IV. In the same Table it is shown that both Francis and Slutsker and Whittaker found the cuneiform present in the Cleveland children at an earlier age.

Our naviculars tend to vary more in onset of ossification than other foot bones. It is interesting to look at Elgenmark's report for the navicular. Its earliest appearance in films of his boys was twelve months, and the latest navicular appeared after fifty-one months. The median onset

age for the group was 38.1 months. Our mean onset age for the naviculars in boys was 30.7 months with a standard deviation of 13.5 months. In other words, the median age of onset in his children is about seven months later than the mean age in our series.

Usually the distal epiphyses of the tibias in children vary less in onset of ossification than most tarsals. Elgenmark listed the epiphysis as appearing at 5.7 months for his fiftieth percentile group. The mean age of appearance for our Research Series boys was 4.3 months with a standard deviation of 1.8 months. This epiphysis must have been somewhat delayed in onset of ossification in Elgenmark's group.

Thus by comparing the two tables bone by bone, we find in general that Elgenmark's age of onset of ossification for his fiftieth percentile group is somewhat later and his range of variation is somewhat greater than analogous onset ages for bones in our Research Series children.

We know of very few studies of intermediate maturity indicators. One of the earliest and most complete studies of their variability in time of appearance was that made by Vogt and Vickers.[27] They used the classical method of assessment, and the films of the Boston children included in Stuart's growth study. At each chronological age, they presented sketches of intermediate maturity indicators to show three developmental levels. These were; the ninetieth percentile sketches or those for the most advanced ten per cent of the children, the modal sketches, and the tenth percentile sketches or those for the ten per cent of the children who were least advanced at the designated age.

If one studies the shape of these sketches as precisely as their small size will allow, it is interesting to note that the dorsoplantar view as depicted for the tarsals in the ninetieth percentile children at four years is almost the same as the sketch presented for the fiftieth percentile at age four and a half and very much like the picture presented for the tenth percentile boys at five years. In other words, this particular level of development had a range of at least one full year.

Similarly, the sketches of the ninetieth percentile boys at five and a half years is very similar to the sketches for the tenth percentile boys a six and a half years except that the epiphysis of the first metatarsal is more advanced in the advanced younger group than in the slowing maturing older group. A curious instance of the variability to be expected in the navicular, in contrast to the first metatarsal, is that the navicular is less mature in the sketch for the advanced five and a half year old children than in the slowly maturing six and a half year old children. Other bones, like the epiphyses of the lateral metatarsals and the second cuneiform, are more advanced in the ninetieth percentile children at five and a half years than in the tenth percentile children at six and a half years.

As standards, the Vogt and Vickers charts show that rapidly maturing children may be expected to have the short bones of the foot at more advanced developmental levels than their tarsals. The short bones and tarsals of the fiftieth percentile children are charted on the same developmental level. In the slowly maturing children the short bones had developed more slowly than the tarsals. Although the authors undoubtedly did not intend these charts to be used as invariable rules, we find that similar patterns of bones of the foot may be expected in rapidly maturing, modal and delayed feet. Moreover, their method of standardizing the intermediate maturity indicator ages differs from the method which we have used to select the indicator series in Parts II and III of this atlas.

Similar age tables for the final maturity indicator of individual bones of the foot are relatively scarce. We have had the privilege of seeing unpublished data and several recently completed studies, among them the data of Stuart and his associates which are based on eighteen year film series.[37] Those data on epiphyseal-diaphyseal fusion resemble our data which form the basis for the table of epiphyseal-diaphyseal fusion in Research Series children which appears with Standard Plate 29.

In addition to intermediate maturity indicator sequences, the major objective of all long-term studies of growing bones has been to provide data concerning the span or length of the osseous stage in individual bone growth centers.

The span is the elapsed time between the appearance of the first and final maturity indicators of the center. The tendency has been to prepare charts based upon the first and final indicators. For example, this objective seems implicit in the charts of Lurie, Levy and Lurie [28] who described one of the first short methods of skeletal age assessment from data of 1129 children age thirty months to nineteen years. These charts show ranges for onset of ossification and epiphyseal-diaphyseal fusion in selected centers of the hand and wrist, elbow, pelvis, knee, foot and ankle.

For the most part, their expected age ranges for onset of ossification are only slightly different from our ranges as shown in the tables in the Appendix although they did not rigidly exclude all children with previous illness from their sample. Before their study appeared in 1943, Francis had published two studies [29, 30] pertaining to the effects of health status on bone growth in selected children from the Brush Foundation Study. These children were similar in age to the youngest groups observed by Lurie, Levy and Lurie. The assessment charts of Lurie, Levy and Lurie include bone growth centers with later onset ages as well. Thus this charting system permits some study of long-term effects of illness during early childhood upon later-appearing onset of ossification.

For example, the chart includes the epiphysis of the calcaneus which began to calcify at 88.6 months, on the average, in our Research Series boys with a standard deviation of 11.5 months. They found an ossification center in the calcaneal epiphyses at ninety-six months in 60 per cent of their boys. These authors had used the classical method of onset age assessment. When we use the same method, our onset age range for this epiphysis becomes fifty-four months to ten years. Their range was sixty months to eleven years. Similarly, the age range for epiphyseal-diaphyseal fusion in the calcanei of our group would be twelve to seventeen years, and their range was thirteen to seventeen years. Our mean fusion age for boys, as shown with Plate 29 in Part II, was 15.8 years with a standard deviation of 1.0 years. Lurie, Levy and Lurie concluded that if a child's rating was found to differ by six months from their chart, such a difference would not warrant a rating of relative advancement or delay.

In evaluating advancement or delay in onset of ossification of a bone growth center, the number of months should be graduated according to the chronological age when the center usually begins to calcify. It is relatively easy to make a rule for epiphyseal-diaphyseal fusion and the corresponding final maturity indicators of tarsals, since they appear much more nearly simultaneously. In this atlas, for example, the first appearance of the initial nodule in the five proximal phalanges of the foot is spread over a period of twelve months (18.6 months for the third toe to 31.0 months for the fifth toe). Yet epiphyseal-diaphyseal fusion occurs in all five of them within a period of six months (15.6 years to 16.0 years). Or, if onset and completion ages of epiphyses of the metatarsals are compared, their initial nodules appear over a period of twenty-four months (28.7 to 53.0 months), but their epiphyseal-diaphyseal fusion is completed within three months (15.8 years to 16.0 years).

For these reasons, the great variability of times of onset of ossification, and the decreasing variability of successive maturational stages, Todd and his associates and those of us who have followed him in the Brush Foundation studies have placed more emphasis upon what we have called "intermediate" maturity indicators, for assessment of skeletal development, either in population studies or in a growth clinic for individual children.

Any "shorthand" method of assessing skeletal maturity, such as counting the number of ossification centers present in a region or lateral half of the body, or of recording the total number of arbitrarily selected maturity indicators, will fail in accuracy because of the overlapping of the initial and early intermediate maturity indicators met with in healthy children. They will also fail to indicate different patterns of development, or the degree of asynchronous development in different parts of a hand or foot.

Similarly, any method which utilizes the measurements of sizes of developing bones, even when expressed as ratios, will fail to take into con-

sideration those differentiation changes in the contours of the bones which characterize development independent of increase in size. Such measurements, even though more objective than the inspection of bone shapes, cannot take into consideration the variations of constitutional types of children, nor the variations in patterns of ossification within regions containing numerous growth centers such as hand and foot.

The inevitable conclusion, it seems to us, is that any summation of a child's skeletal maturity, while some of its bones are still in the onset of ossification stage and others are well modelled and already on more similar development levels, must be by reference to a radiographic standard rather than to a summation scale consisting of mixed forms of maturity indicators.

If the assessor of skeletal maturation will have patience and perseverance to identify the cardinal indicators of each bone among its intermediate indicators, he will find our standard plates much less difficult to use. If, further, he then records the assessments of the individual bones, he can repeatedly summarize the different patterns of development of children or of the several osseous regions of the same child. Such a summation is made in the graph in Figure 5 from x-rays of the foot of boy No. 49 in the Stuart Growth study.

In the graph, the heavy row of dots indicates

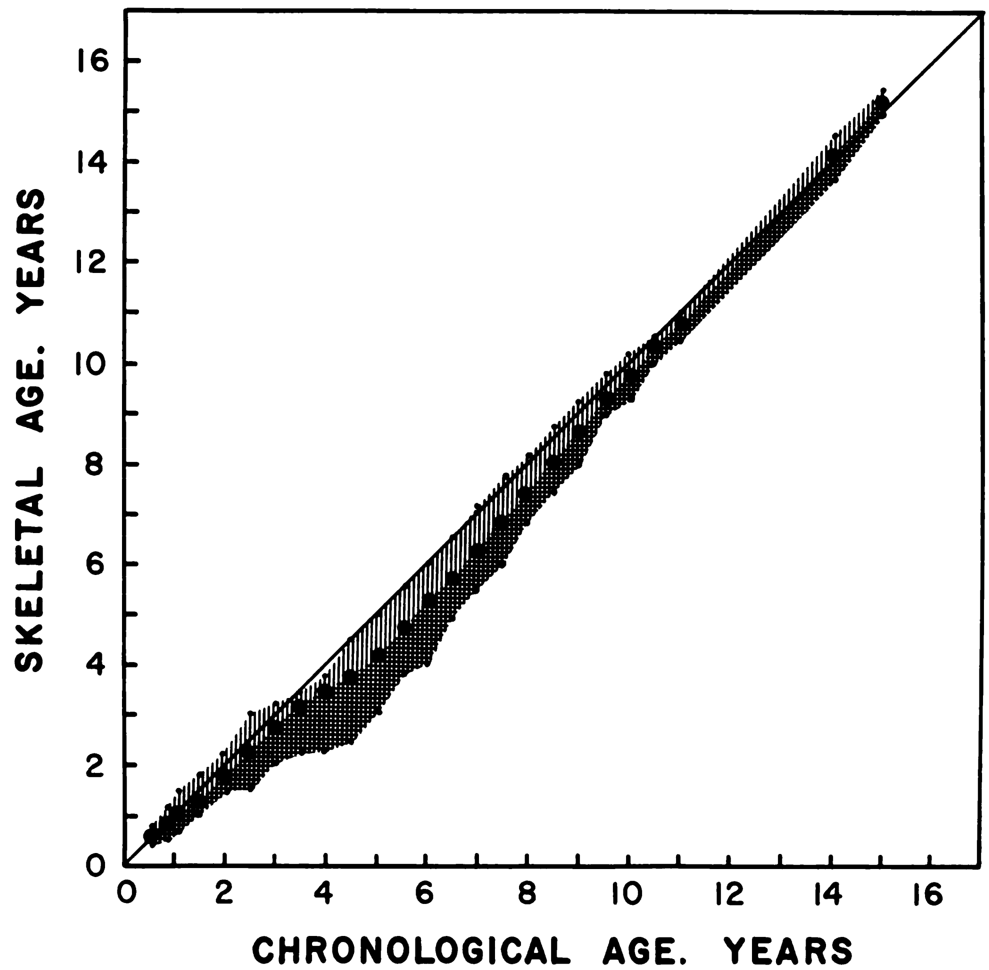


Figure 5. The developmental range graph of the right foot of a boy whose films were assessed according to the standard of reference in Part II. (Courtesy of Dr. Harold C. Stuart, Boston, Massachusetts. See pages 910, 917, 932 and 962, Boy Case 49, in reference 34 for further information on his growth, health and nutritional progress.)

skeletal age (foot). The upper row of fine dots indicates successive developmental levels of his most advanced centers, the lower row the developmental level of his least advanced centers. This boy had no serious illnesses during his childhood. However, during the interval when he was three to six years old, his family suffered severe financial hardship. During this period his developmental range graph shows asymmetry between the most rapidly developing bones and the least rapidly developing bones of as much as two years. In addition, his average skeletal age from being very close to the standard, fell below the standard about 0.7 year. During his third to fifth years, his average skeletal age was near the top line of the graph, indicating that at first only a few bones were retarded in development. Later, however, the average skeletal age lies about halfway between the top and bottom lines, indicating approximately equal numbers of bones above and below the average skeletal age.

From the age of ten years, his developmental range graph is quite narrow and his average skeletal age expresses the range quite well.

V Handicaps to Optimal Development of Individual Bones; Variant Ossification Centers

IT HAS LONG BEEN KNOWN that any traumatic experience or disease which causes a temporary retardation in skeletal development may leave a transverse line of greater density in some of the long bones. These "bone scars" are most readily seen in the distal ends of the radius and tibia. The scars in the tibia were quite evident in the children who survived the atomic bombing of Hiroshima and Nagasaki, as reported by Greulich, Crismon and Turner.[31]

During the '30's many of the Brush films were made with softer x-rays than are used in routine hospital radiology departments. In the Brush films we can accordingly see many more of the transverse bone scars in the distal end of the tibia than are seen in some studies. For example, a scar is seen in the tibia of the most rapidly developing boy of the ten year old group in Figure 18. In instances like this a scar may appear following an acute illness of short duration even though there is no other evidence of delayed skeletal development.

Francis[30] also showed how the onset times may be delayed by disease. The ages of onset of ossification of certain centers have such a great standard deviation that it may be difficult to note the effect of illness in retarding the development of bone unless the illness is quite severe or prolonged.

Between the beginning and the end of osseous development children may differ greatly in the rate of development of individual bones. Advanced and delayed nodules of ossification are apt to differ in the smoothness or roughness of outline in the radiograph. Any nonarticular portion of the outer bone margin of a center of ossification in particular is apt to be "thinned or roughened" in the radiograph, thereby leading to the impression of poor mineralization. What we have called disseminated calcification, to which attention is called at the appropriate stages of development in the standard plates in Part II, may be seen either during accelerated or retarded ossification of some of the bones of the foot, and is a normal process.

The navicular, in particular, may in late childhood appear as a thin disc or have a fuzzy outer bone margin. Subsequently the navicular may develop very rapidly, and by the thirteenth to fifteenth year has the same appearance as the naviculars in the radiographs of our standard plates. If a child has signs and symptoms of disease referable to a given bone, and if an x-ray of this bone shows defective ossification, the disease may be diagnosed as osteochondritis or osteochondrosis. The adult contour of the bone may be altered although the progress of the disease has been halted. The condition we have called disseminated calcification in long and short bones and compound onset of ossification in round bones is a normal process. It is never accompanied by signs and symptoms of disease and the adult contour of the bone is not altered.

In Figure 6 is illustrated the foot of a girl of nine years who was born with spina bifida and who was paralyzed in both lower extremities, and for comparison the foot of a healthy girl of the same age. The bones of the foot of the paralyzed girl are poorly mineralized. There are fine lines of increased density within the outer bone margins of many of the tarsals and in the distal end of the tibia, and the shadows of the trabeculae are delicate. Nevertheless, the bones have fairly typical contours and most of the usual maturity indicators to be found in the feet of healthy children. In Table VI are listed the

data on the onset of ossification of the bones of the foot of this girl and there are some significant variations in order of onset as well as general delay. At nine years her foot was retarded about two years in skeletal development.

Figure 7 shows the films taken at the age of ten years of a boy who had only one phalanx for each toe. The metatarsals, and the bones of the midfoot and hindfoot are much as usual, and can be used in arriving at an assessment of skeletal age.

Figure 8 presents the lateral film of the foot of a boy born with one club foot. This film was made several years after an attempt had been made to correct the deformity by plaster-cast therapy. In the midfoot and forefoot the bones have much the usual shapes and enough of the maturity indicators can be seen to give an approximate skeletal age assessment. By comparison with the standard plates it can be seen, if one assesses by midfoot and forefoot alone, that this boy's skeletal development has not been very much delayed in comparison with the average boys of his chronological age.

Even with extreme deformity, there is usually enough typical and recognizably individual shaping of some of the bones to allow for an estimate of skeletal age. One is forced to discount the variant bone from the calculation of skeletal age. One then arrives at an average skeletal age for the foot as a whole by using the assessment of the remaining more typical bones. While this procedure probably leads to a much less precise assessment of skeletal age and to difficulty in assessing the degree of asynchrony in the development of individual bones of the foot, nevertheless it should be accurate enough for the purposes of the orthopedic surgeon and pediatrician. If a bone has much the typical individual shape but has an additional center of ossification, one uses the over-all shape, including the contours of the accessory center of ossification, in arriving at an assessment of the maturation of the bone.

As numerous investigators studying children have discovered, it is often difficult to fit the film of a sick child to any one of our standard films. Following the development of all the individual bones prevents the assessor from making a partial or biased assessment, except as he decides from his experience to place more or less importance upon the development of certain bones of the foot. Jones and Dean[32] studying children who have suffered from kwashiokor, found that it was not helpful to record the average skeletal age for their children. They were forced to assign separate skeletal ages to each of the various bones of a film, in order to obtain an accurate concept of the development of the individual.

As was suggested in the 1950 atlas on the development of the hand, if a film cannot be fitted exactly to one of the standard films in the atlas, it is often useful to assess the separate bone age of the least advanced bone and the most advanced bone of a region. This degree of asynchronous development may be an additional clue to the degree the child has suffered from nutritional deficiency or from disease.

Occasionally a bone of the foot may have a bizarre pattern of ossification. In Figure 9, we illustrate a calcaneus which developed from several separate main (regularly occurring) centers of ossification. As the child grew older these centers fused and the silhouette became that of the usual calcaneus. Figure 10 illustrates a calcaneus which had three separate main centers of ossification. The calcaneus began to assume a more typical contour by two years, and the parts were practically fused by two and one-half years. Thereafter the calcaneus displayed the same individualities of shape which are usually seen and developed its regular secondary center in the epiphysis by the age of nine years. In Figure 11 is illustrated a calcaneus with a small posterior, accessory primary center of ossification. This center had fused with the main primary center by three years and the true epiphyseal center appeared by seven years.

Another variant seen rarely is a cuboid (Figure 12) arising from two centers of ossification. In Figure 13 is illustrated a long, slender talus, which may have incorporated the center of ossification of the navicular. It will be noted that the calcaneus in this film is also long and slender.

TABLE VI

CHRONOLOGIC AGE AND ORDER OF ONSET OF OSSIFICATION IN THE FOOT OF A GIRL WITH SPINA BIFIDA

Ossification center	*Usual order of onset of ossification*	*Mean age of onset of ossification (months)*	*Paralyzed girl order of onset of ossification*	*Age of onset of ossification (months)*
Calcaneus, Body	1		1	
Talus	2		2	
Cuboid	3		3	
Lateral cuneiform	4		6	18
Tibia, Distal epiphysis	5	3.7	4	5 ?
Fibula, Distal epiphysis	6	8.7	5	17
Toe I, Distal phal. epiphysis	7	9.4	12*	34
Toe III, Prox. phal. epiphysis	8	11.2	7	21
Toe IV, Prox. phal. epiphysis	9	12.4	8	22
Toe II, Prox. phal. epiphysis	10	13.2	10	25
Medial cuneiform	11	15.6	14	37
Toe I, Prox. phal. epiphysis	12	18.1	11	33
Intermediate cuneiform	13	19.1	13	36
Metatarsal 1, Epiphysis	14	19.2	15	38
Toe V, Prox. phal. epiphysis	15	20.1	22*	63
Navicular	16	21.4	9*	22
Metatarsal 2, Epiphysis	17	24.0	19	54
Metatarsal 3, Epiphysis	18	28.6	20	54
Toe IV, Distal phal. epiphysis	19	28.9	17	46
Toe III, Distal phal. epiphysis	20	32.8	16	39
Metatarsal 4, Epiphysis	21	33.2	21	60
Toe II, Distal phal. epiphysis	22	35.1	18	47
Metatarsal 5, Epiphysis	23	38.5	23	72
Calcaneus, Epiphysis	24	60.0	24	102

* The order of onset of ossification in these centers seems to be significantly different from the order of onset of ossification of these same centers in feet of normal girls observed by Slutsker and Whittaker. See Tables in the Appendix.

Figure 6. Development of the nonfunctioning foot. The upper picture is that of the lateral radiograph of a girl at the age of nine years who was born with spina bifida and whose lower extremities were paralyzed from birth. The lower picture is that of a healthy girl of nine years. See text for further discussion. Also see Figure 5 of knee atlas.[3]

Figure 7. Radiographs of the left foot of a boy of ten years who had only a single phalanx for each toe.

Figure 8. Lateral radiographs of a boy at age 14 years with a congenital clubfoot.

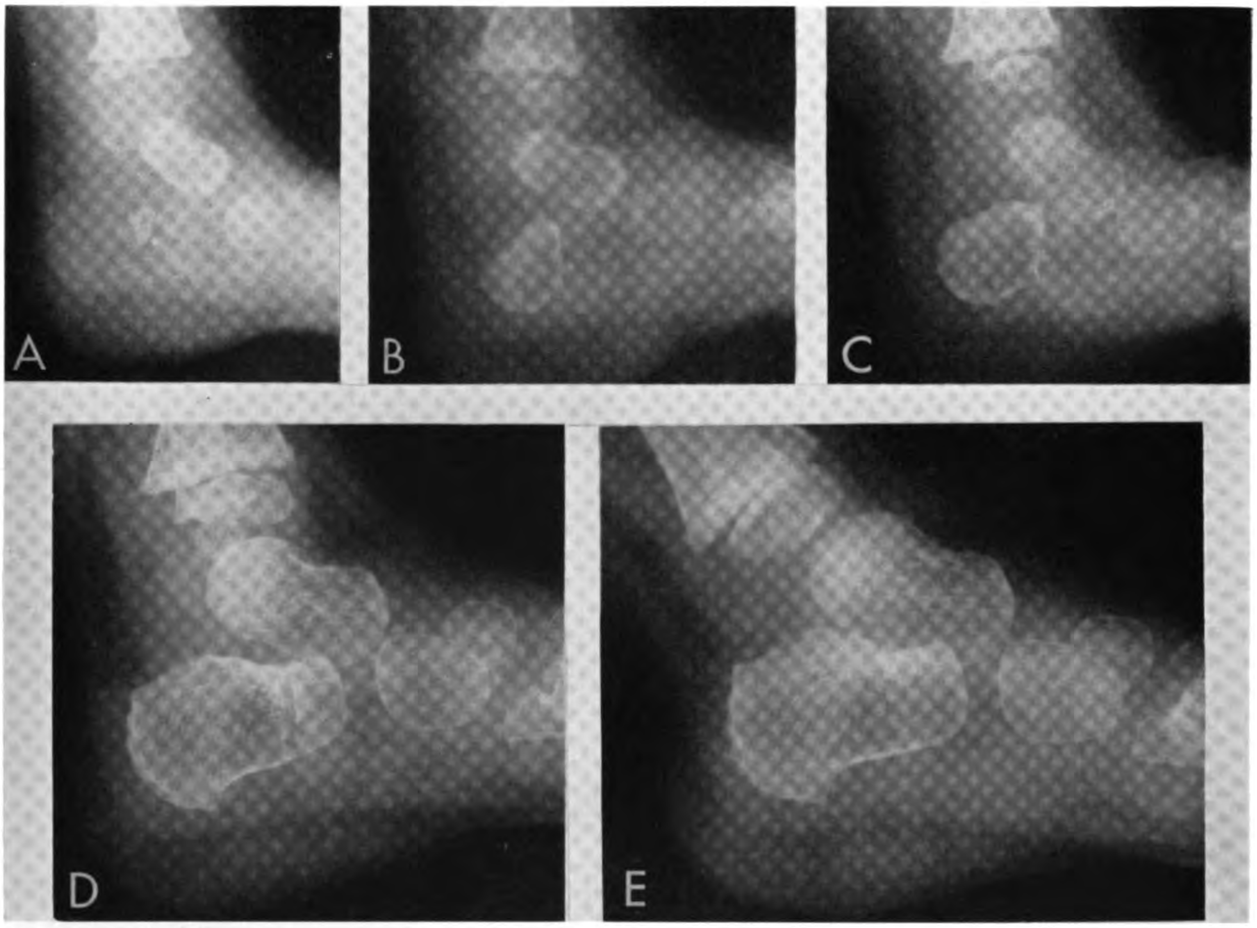


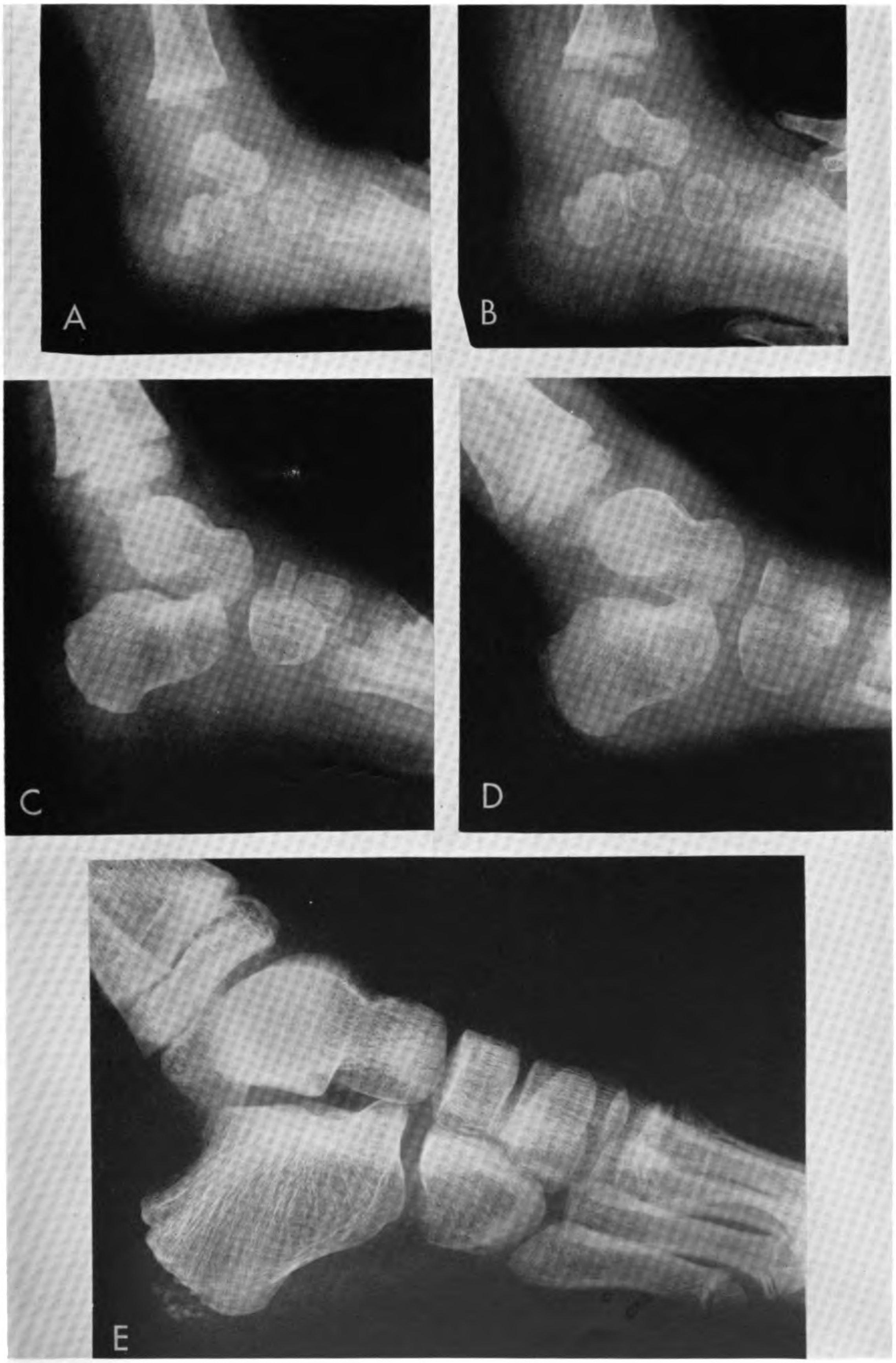
Figure 9. Multipartite calcaneus. Illustrated are five successive stages in the development of a calcaneus which ossified from several primary centers of ossification. At first only the posterior portion of the bone was ossified, later another center appeared in the anterior portion of the bone. In the last film at two years and six months the two centers were almost completely fused and the general contour of the silhouette was not unusual. (See Caffey,[20] Figure 868.)

A. Three months
B. Six months
C. Nine months
D. Two years
E. Two years and six months

→

Figure 10. Multipartite calcaneus. Illustrated are successive stages in the development of a calcaneus which ossified mainly from three primary centers of ossification. Notice that in the film at six months, the major nodule is directly below the ankle joint. By thirty months these centers had fused and the general contour was typical. At nine years the center for the epiphysis had appeared in its typical position. (See Caffey,[20] Figure 868.)

A. Six months
B. Nine months
C. Two years and six months
D. Three years and six months
E. Nine years


A
B
C
D
E

←

Figure 11. Accessory primary calcaneal center of a boy at nine months, twelve months and seven years. The extra center, having the appearance of a true epiphyseal center at nine months, formed between the posterior margin of the primary ossification center and the epiphysis, was not visible at three months or six months. This extra center had completely fused with the main primary center by three years. The true epiphyseal center was visible at seven years. Note that it appeared in the same plane as did the accessory center.

Figure 12. Bipartite cuboid. Illustrated are dorsoplantar views of the left foot of a boy at six months and twelve months. At six months the cuboid showed two distinct centers of ossification. At twelve months the two centers had completely fused. At three months (not shown) no centers of ossification were visible in the cuboid or lateral cuneiform; according to expected age of onset of ossification both bones were significantly delayed, especially the cuboid. After one year, development proceeded quite uneventfully.

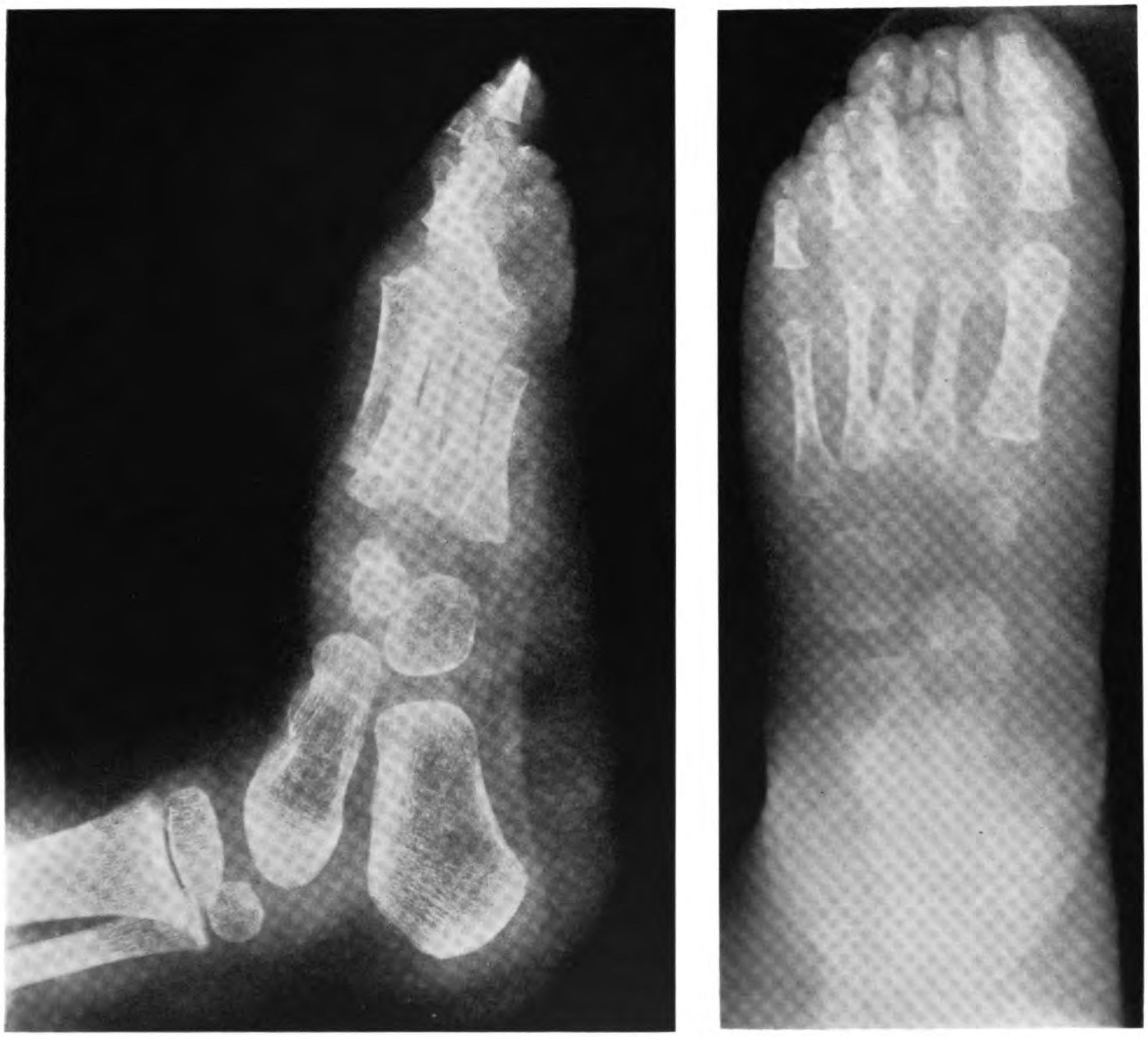


Figure 13. An abnormal talus. On the left is the lateral view of the left foot of a girl at two years two months of age, and on the right is the dorsoplantar view of the same foot at two years five months. The talus is very long and slender. In the dorsoplantar view it is clear that a large anterior nodule is fusing with the main center of the talus. This probably represents a fusion of navicular with talus although the navicular may still be entirely cartilaginous at this age. However, the space anterior to the nodule where a cartilaginous navicular would be located is very narrow.

VI Regularly Occurring and Accessory Bone Growth Centers

A REGULARLY OCCURRING BONE CENTER is one which is not sex-limited, race-limited or generation-limited, that is, it is potentially present in every child. An accessory bone growth center is one which is not present in every child.

If for the sake of discussion we consider that the bones of the foot and ankle consist of tibia, fibula, seven tarsals, five metatarsals, fourteen phalanges and two sesamoids of the great toe, there are thirty regularly occurring primary ossification centers. If we assume that tibia, fibula, metatarsals and phalanges each have an additional epiphyseal center there are twenty-one more of these. In addition, there are secondary centers for the calcaneal epiphysis, for the posterior border of the talus and for the proximal end of the fifth metatarsal making a total of fifty-four regularly occurring ossification centers in the foot and ankle.

Many of the phalanges show a wide variation in developmental pattern. The middle phalanges of the lateral toes, in particular, often do not have a separately appearing secondary center of ossification. What may appear to be the epiphysis occurs by budding from the shaft. Therefore, in Part II we have omitted the middle phalanges of the four lateral toes from our considerations of skeletal age assessment. Because of the difficulty of properly positioning the four lateral toes, the distal phalanges of toes two to five frequently are not very useful in determining skeletal age.

The regularly occurring center of ossification in the epiphysis of the calcaneus is utilized in the determination of skeletal age and its development is described in Parts II and III. An upper or secondary nodule in the epiphysis of the calcaneus is now generally recognized as a constant center of ossification and has been discussed by Harding.[26]

We have found a separate center of ossification in the posterior border of the talus almost constantly in the films of our Brush Foundation children in late childhood and early adolescence. We have been able to distinguish this separate center of ossification so routinely in boys between the ages of eleven and thirteen and in girls between the ages of eight and ten years that we consider it an epiphysis of the talus. If this center remains separate from the talus in the adult, it is then called the os trigonum. For the sake of convenience in this atlas, we have called this center the os trigonum whether it fuses with the talus or not.

Of 100 adolescent Brush girls the os trigonum remains separate at the adult stage in 18 per cent, and in 100 adolescent Brush boys, in 14 per cent. If we remove from our calculations those children in whom the os trigonum remains separate in adult life we obtain the following figures for onset and fusion. The center of ossification of the posterior border of the talus appears at 8.1 ± 1.3 years in girls and at 11.1 ± 1.9 years in boys. It fuses with the primary center of the talus at 9.8 ± 1.3 years of age in girls and at 12.9 ± 1.3 years of age in boys. After it has fused it helps to form the posterior process of the talus.

We also consider the secondary center in the proximal end of the fifth metatarsal a constant center of ossification—the os Vesalianum. Of the 100 adolescent Brush boys and the 100 adolescent Brush girls whose films were used in setting up our standard plates, we have failed to see such a center in only two of the girls. In all of the other 198 children, this accessory center of ossification fused with the fifth metatarsal. This secondary center appears in girls at the age of 9.7 ± 1.2 years and in boys at the age of 12.1 ± 1.3 years. It fuses with the shaft of the

fifth metatarsal at the age of 11.7 ± 1.0 years in girls and the age of 14.2 ± 1.1 years in boys.

Sesamoid bones are often listed with accessory bones. They are, however, not additional centers of ossification of the regularly occurring bones like the bones discussed thus far, but are bones which develop in tendons. There are two under the distal end of the first metatarsal; these are constant. The only variation to be seen with any noteworthy frequency is their compound onset of ossification, the frequency of which is shown for the Research Series and Boston children in Table VIII. Either one or both sesamoids may be derived from multiple centers of ossification. The variations in these two sesamoids of the great toe have been studied at the young adult level in the entire Brush Foundation series by Hubay.[33]

The other sesamoids, the interphalangeal and metatarsophalangeal nodules of the four lateral toes, are usually quite small when present and are not readily apparent in x-ray films at onset of ossification.

The foot more frequently than any other region of the body shows ossification centers in addition to the regularly occurring centers mentioned above. Many of these supernumerary centers of ossification fuse with the rest of the (regularly occurring) bones to which they belong. Sometimes, however, these supernumerary centers of ossification remain separate from nearby bone; they are then called accessory bones in the adult.

More than fifty accessory bones in the foot have been described. Figure 14 shows the location of certain of the accessory bones. In our material and in the films of the Stuart collection only eighteen or twenty of these accessory centers of ossification have appeared as frequently as one per cent. Most of them in boys are seen between the ages of ten years and fifteen years and in girls between the ages of eight and twelve. They are of especial interest to the radiologist who must distinguish them from fractures. Their frequencies of occurrence have been listed in Table VII.

Of great clinical interest is the os tibiale externum or accessory navicular. This is a separate center of ossification for the tuberosity of the navicular. In Figure 15 are illustrated the feet of two girls who had accessory navicular bones. In Figure 16 is illustrated the occurrence of a familial tendency to have an accessory navicular.

Figure 17 has been supplied by the courtesy of Dr. Harold C. Stuart and illustrates the appearance, development and final fusion of a secondary center of ossification in the medial malleolus.

TABLE VII

ACCESSORY BONES OF THE FOOT AND ANKLE AS OBSERVED IN 367 RESEARCH SERIES CLEVELAND CHILDREN AND 134 MATURITY SERIES BOSTON CHILDREN. FREQUENCY OF OCCURRENCE EXPRESSED IN PER CENT

Name of bone in conformity with Nomina anatomica terminology, 1955:	*Boys*		*Girls*	
	Cleveland	*Boston*	*Cleveland*	*Boston*
Calcaneus secundarius	11	7	6	7
Os aponeurosis plantaris	1	0	1	0
Os cuboideum secundarium	1	0	0	3
Os cuneometatarsale I tibiale	1	3	1	2
Os cuneonaviculare I dorsale	*	11	*	10
Os intercuneiforme	1	0	1	0
Os interphalageale I and II	4	3	4	3
Os paracuneiforme	—	11	0	11
Os peronaeum	3	3	1	3
Os subfibulare	2	7	2	10
Os subtibiale	—	3	—	2
Os supratalare	1	2	0	0
Os sustentaculi	2	3	0	0
Os talonaviculare dorsale	*	15	*	11
Os talotibiale dorsale	1	2	0	0
Os tibiale externum	4	9	8	3
Os trigonum	14	25	18	22
Os Vesalianum pedis	1	2	0	0
Subcalcaneus	1	2	0	0

* Data not available.

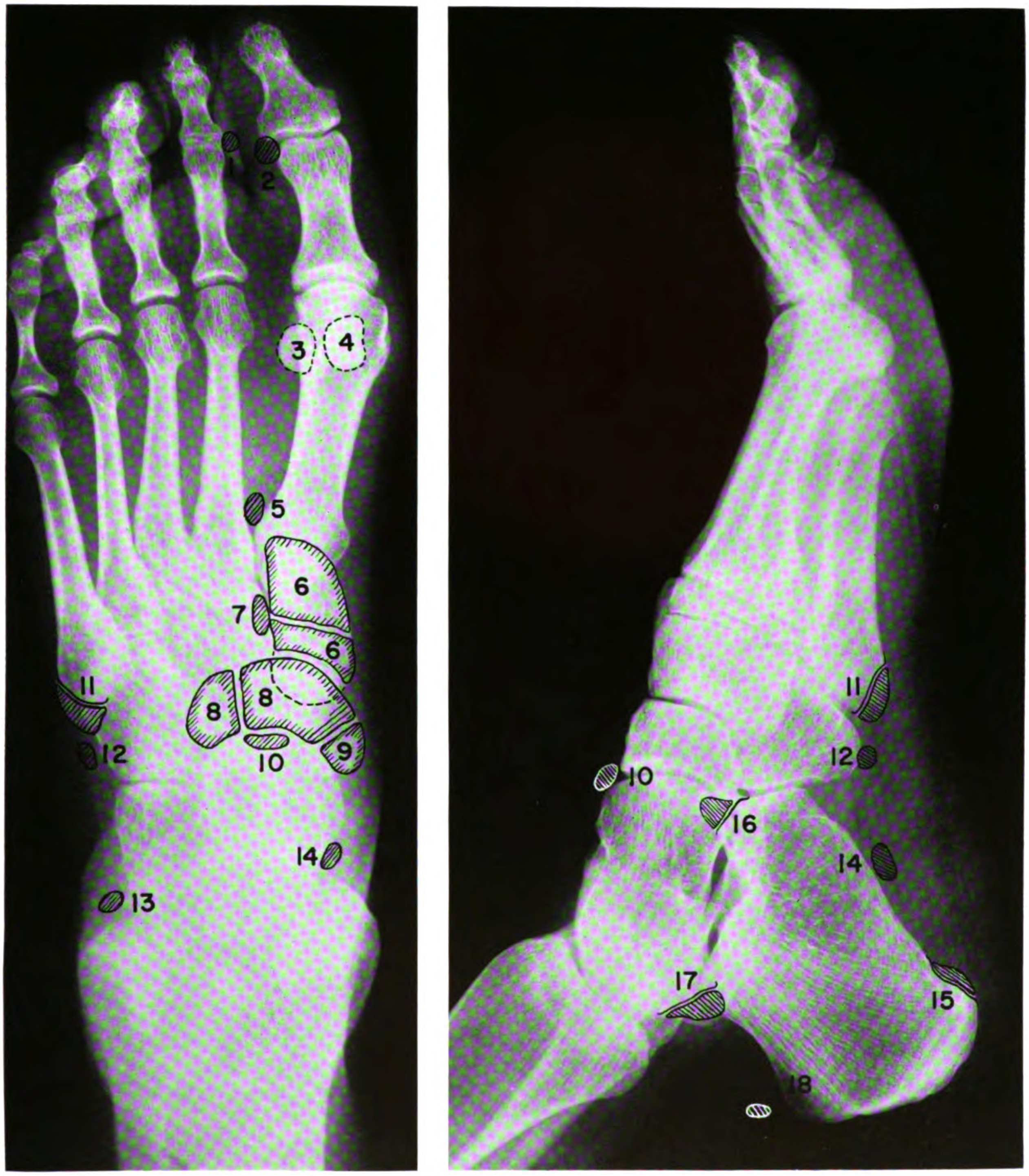


Figure 14. Diagram of certain accessory bones of the foot. This figure has been adapted from Trolle [18] and O'Rahilly.[19]

1. Os interphalangeale II
2. Os interphalangeale I
3. Lateral sesamoid, toe 1 (fibular side)
4. Medial sesamoid, toe 1 (tibial side)
5. Os intermetatarsale 1
6. Os cuneiforme mediale bipartitum
7. Os intercuneiforme I and II
8. Os naviculare bipartitum
9. Os tibiale externum (naviculare accessorius)
10. Os talonaviculare dorsale
11. Os Vesalianum pedis
12. Os sesamoideum peronaeum
13. Os subfibulare
14. Os subtibiale
15. Os tuberis calcanei
16. Calcaneus secundarius
17. Os trigonum (separate in adult stage)
18. Os tendinis calcanei

Figure 15. Accessory naviculars. The left hand view is that of a girl age twelve years and the right hand view is that of a girl age 14 years. Each nodule had begun to ossify before age ten years when their film series was begun. The nodules remained separated after epiphyseal-diaphyseal fusion was completed throughout the foot and ankle.

Figure 16. Familial accessory navicular. There were four children in the family, three girls and one boy. The left-hand film shows the foot of the oldest girl; the right-hand film shows the foot of the second girl in the family. The films of the third girl showed no evidence of any accessory nodule. The boy's films showed a *first* accessory nodule at age six years six months, which had united with the major nodule by age eight years six months. At age twelve (his last film), another nodule similar in shape and location to that of his sister as shown in the right-hand film was forming.

TABLE VIII

ONSET AND COMPLETION OF THE OSSEOUS STAGE OF DEVELOPMENT OF THE OS TRIGONUM, OS VESALIANUM, MEDIAL MALLEOLUS (TIBIA), AND SESAMOIDS BENEATH THE DISTAL END OF THE FIRST METATARSAL. 200 CLEVELAND RESEARCH SERIES ADOLESCENTS AND THE 134 BOSTON MATURITY SERIES CHILDREN (34).
AGE IN MONTHS

	Cleveland Boys					*Boston Boys*				
Bone growth center in:	*No. of boys*	*Onset: Mean*	*Onset: S.D.*	*Completion: Mean*	*Completion: S.D.*	*No. of boys*	*Onset: Mean*	*Onset: S.D.*	*Completion: Mean*	*Completion: S.D.*
		Months					*Months*			
Os trigonum	70	133	21	155	16	43*	115	14	147	19
Os Vesalianum	100	145	16	171	13	58*	145	16	169	13
Medial malleolus	—	—	—	—	—	39*	106	19	131	18
	Cleveland Girls Months					*Boston Girls Months*				
Os trigonum	100	97	16	118	16	46*	92	13	123	21
Os Vesalianum	100	116	14	140	12	58*	120	12	145	16
Medial malleolus	—	—	—	—	—	47*	92	13	115	9

	Cleveland and Boston Boys						
	At onset of ossification:					*Single nodule at maturity:*	
Sesamoids beneath first metatarsal:	*No. of boys*	*Mean (months)*	*S.D.*	*Range*	*Multiple nodules per cent*	*No. of boys*	*per cent*
Fibular side	114	138	15	99–174	30	167	86
Tibial side	114	140	15	99–178	51	167	66
	Cleveland and Boston Girls						
Fibular side	127	107	21	82–150	29	167	92
Tibial side	127	110	21	83–150	33	167	86

* The study was interrupted for all children in this group in 1942-1943, thereby preventing assessments for those Mautrity Series children whose bone growth centers attained this developmental stage during those years.

→

Figure 17. Secondary center of ossification in medial malleolus. These are films of the right and left ankles of a girl at eight, nine and ten years and of the right ankle at 18 years. In the nine year film there is clearly visible a secondary center of ossification in the lower border of each medial malleolus. Each of these secondary centers fused with the main ossification centers for the distal tibial epiphysis before epiphyseal-diaphyseal fusion occurred. For frequency and age of occurrence in the Boston Film Series see Table VII (Courtesy of Dr. Harold C. Stuart, Boston, Massachusetts).


OF CHILD
OF CHILD

←

VII Design of the Standard of Reference

"IF ONE COMPARES A RADIOGRAPH of an adult bone with the bone itself, silhouettes of the various surface markings can be identified. Similarly, radiographs of any child's knees, taken at ten consecutive birthdays and arranged in order of chronological age, will reveal that the silhouettes of the epiphyses and sub-epiphyseal surfaces of the diaphyses possess orderly series of characteristic, increasingly mature osseous contours. Only some of these characteristic changes in bone contours of the knee will be visible from the two standard views given in subsequent pages, but after identification, these changes can be used to assess the level of development of any child's knee. Such changes are skeletal maturity indicators." (Ref. 3, page 7.)

The foot standard, like the standard of reference in the knee atlas, consists of two views of the foot and ankle plus the skeletal ages assigned to the individual bones therein. The anatomical scale for each bone is derived from the several maturity indicator series in portions of its cortex.

Obviously every skeletal maturity indicator which we have standardized must prove to be universal in all normal feet if this standard of reference is to be used for assessment of feet of all races. The contours of each bone, in the selected radiographs, must be quite typical for children in general. The rate of ossification shown by the individual bone age series must be the same for every bone; in this as well as in the preceding atlases we have named the developmental rate a moderate rate.

The preparation of our standards in this laboratory began with acceptance of the fact that a maturity indicator series *per se* is a developmental scale. However its application requires acceptance of another fact; any series of indicators will fail to reveal a child's developmental level apart from proper combination of its skeletal age and chronological age (Todd,[1] page 22). The linkage between skeletal age and chronological age has been discussed in detail by Greulich and Pyle.[2] Individual bone ages were found as necessary for the foot standard as for the hand standard since the region contains so many bones and onset of ossification therein extends throughout childhood. It has always been accepted in this laboratory that a two-part standard, that is, a set of plates for the male and a set of plates for the female, can be condensed to a single standard without loss of the essential attributes of the doubled standards like those of Todd [1] and of Greulich and Pyle.[2] Such condensation was first attempted with the knee standard in 1955,[3] and the foot standard in Part II of this atlas is also a single standard.

Briefly, the designing of the single standard proceeded as follows. Radiographs of the foot had been made at three, six or twelve month intervals. Accordingly, films of 100 boys and 100 girls at each examination (chronological) age from birth to eighteen years were selected from approximately three times this number. Our Research Series of 515 boys and 484 girls [35] has included the Brush Foundation children with the best health histories. Since all developmental examinations had been scheduled according to birthdays, it was relatively easy to assemble a set of 100 foot films at each age which did not differ chronologically among themselves by more than two per cent.

We now repeatedly arrayed in order of their attained development each 100 films using as guides those indicator series of individual foot bones listed in Part III of this atlas. We began with the calcaneus. The process was repeated for

each tarsal, all metatarsals, all phalanges with regularly occurring bone growth centers, and the distal ends of the tibia and fibula. As soon as each array was completed, we bunched the 100 examples of the bone according to developmental stages. Eventually we bunched the films into stages of development for the foot as a region.

The central level-of-development films were named "anatomical mode films." Each standard plate was chosen from such a group, and we now had a two-part or doubled standard of reference, that is, a foot standard for boys and a foot standard for girls, respectively, each consisting of twenty-six plates spaced at three, six or twelve months intervals.

The following explanation from page eleven of our knee atlas,[3] describing the next step in the preparation of this single standard, has been adapted for this foot atlas.

It has been established by preceding observers in this laboratory and elsewhere that numerous human maturity indicators are not sex-limited. Since this is presumably true for the foot, we have combined the twenty-six male anatomical modes and the twenty-six female anatomical modes into a single foot standard consisting of thirty plates applicable to both sexes.

To test the assumption that the maturity indicators which we chose are not sex-limited, the fifty-two anatomical modes were arranged in order of their maturity. In essence, this was repetition of the way in which each set of 100 films had been ranked originally. We found neither a typical male anatomical mode nor a typical female anatomical mode, in terms of skeletal maturity indicators, when chronological age was disregarded. The feet of boys and girls differ naturally in speed of bone growth, and the elapsed time between appearance of sequential maturity indicators is longer for boys than for girls. Consequently, the combining of standard plates permitted a more inclusive series of intermediate maturity indicators than those in either the male or the female standard.

How did we arrive at the double sets of bone ages and skeletal ages for boys and girls, respectively, which are an integral part of each standard plate?

It is readily understood that we did not change the original skeletal age of each standard Plate (male) and standard Plate (female). Such a change would have destroyed the foundation for this single standard of reference. The necessary changes were begun by arranging the fifty-two Plates in order of maturity, disregarding the original sex designation.

The array clearly demonstrated that certain plates from the male standard represented the same or nearly the same developmental levels as certain plates from the female standard. These approximate pairs, of course, did not carry the same skeletal age. Hence just before we reduced the array of fifty-two Plates to the thirty single standard Plates in Part II of this atlas, we assigned a second skeletal age to each plate. As an example of how this was done; we had decided to include the anatomical mode (male) eight years as a standard Plate. We then assessed this film according to the female standard and obtained a skeletal age of six years three months. This age equivalent appears on the standard plate as "Female, six years three months." In effect we merely transferred this skeletal age (female foot) to the film which constitutes Plate 20 in our standard. Each table of bone ages was thus obtained by assessing the chosen standard plate according to the appropriate part of the original two-part standard.

When a standard of reference of this kind is finished, it must resemble a series of films of a child from birth to maturity. The choice of the age intervals between our standard plates depended ultimately upon the lifetimes of individual maturity indicators, that is, the elapsed time between two consecutive maturity indicators of each bone growth center. As mentioned above in this chapter, the length of time between appearance of sequential maturity indicators is predominantly longer in the male foot than in the female foot. Thus the lifetimes of the same indicators in the male foot and the female foot obviously necessitated more validation than any other attribute of this single standard of reference during the final steps of its preparation.

No doubt the reader is as interested as we

TABLE IX

An Evaluation of the Standardized Calcaneal Epiphyses and Naviculars in Plates 15 to 30 According to 100 Films of Eight Year Old Boys and 100 Films of Ten Year Old Boys. Number of Calcanei and Naviculars Bunched Between Pairs of Standard Plates or Matching a Single Plate

	Epiphysis of calcaneus at		*Navicular at*	
Standard plate by number:	*8 years*	*10 years*	*8 years*	*10 years*
	Number of films in each bunch:			
Between 15 and 16			2	0
Between 16 and 17			2	0
Between 17 and 18			1	0
Between 18 and 19			5	0
Between 19 and 20	31	1	27	1
Matched 20	20	1	11	4
Between 20 and 21	13	1	30	5
Matched 21	17	6	5	5
Close to 21	4	6	6	2
Close to 22	5	8	3	4
Matched 23	4	12	2	7
Between 23 and 24	0	15	0	19
Close to 24	0	15	2	27
Matched 24	2	10	0	8
Between 24 and 25	1	16	2	12
Between 25 and 26	2	4	1	2
Between 26 and 27	1	2	1	1
Between 27 and 28	0	2	0	2
Between 28 and 29	0	1	0	1
Number of developmental stages	11	15	15	15

were in the number of maturity indicators of each bone which we found in each set of 100 films of children of the same age and sex. Space does not permit tabulation of the stages, bone by bone, which we found. Table IX contains an example of the developmental stages observed for the calcaneus and the navicular.

We had selected the calcaneal epiphysis and the navicular at age eight years and ten years to test the consecutive nature of the single standard of reference which must be the primary attribute of a standard of this kind. We have used ranked arrays of films based on these two bones of the foot for answers to the following two questions.

Epiphyses tend to show their greatest age scatter at onset of ossification. Does an epiphysis which begins to ossify at the stage when surrounding bones are well advanced in the modeling process display such age scatter? The calcaneus has an epiphysis which begins to calcify at such a stage. Also, in the initial stage of the Brush Foundation studies, Todd and his associates observed that naviculars tend to display erratic schedules for some time after their onset of ossification. Did this tendency again appear in the naviculars which we studied?

According to our table for onset of ossification for boys in the Appendix, the calcaneal epiphysis may be expected to begin to calcify between ages seven and nine years. The navicular reaches the osseous stage three to four years earlier, as a rule. Accordingly, a few naviculars may be expected to display ossification schedules differing from surrounding bones as late as eight years.

As a test of our agreement in ranking films, two of us (N.L.H. and S.I.P.) had independently ranked approximately 300 calcanei and 300 naviculars of Cleveland and Boston boys. For this test we concentrated on films made at eight years and ten years, respectively. We then reduced the number of films to 100 by drawing out every third film in each array. Incidentally, it was encouraging to find that we had placed 89 calcanei and 84 naviculars, at age ten years, in the same position in our arrays of these 100 films. Next we fitted our standard Plates 15 to 30 in Part II within the arrays according to the stage of development of the calcanei and the naviculars in these plates. The number of films which appeared between these consecutive standard plates of one array (that of N.L.H.) has been summarized in Table IX.

We did not find that either the epiphysis or

the navicular displayed an unusual number of developmental levels for this stage of growth. At eight years, the 100 calcaneal epiphyses were on eleven developmental levels and the 100 naviculars were on fifteen levels. But it must be mentioned that 51 per cent of the calcanei either displayed no epiphyseal bone nodule, by age eight, or the osseous particles were barely visible. Thus only forty-nine calcanei could be ranked according to osseous features of the epiphysis itself. By age eight years, all naviculars showed coalescing ossification centers and the 100 films could be ranked according to the several characteristic indicators next in series after onset of ossification.

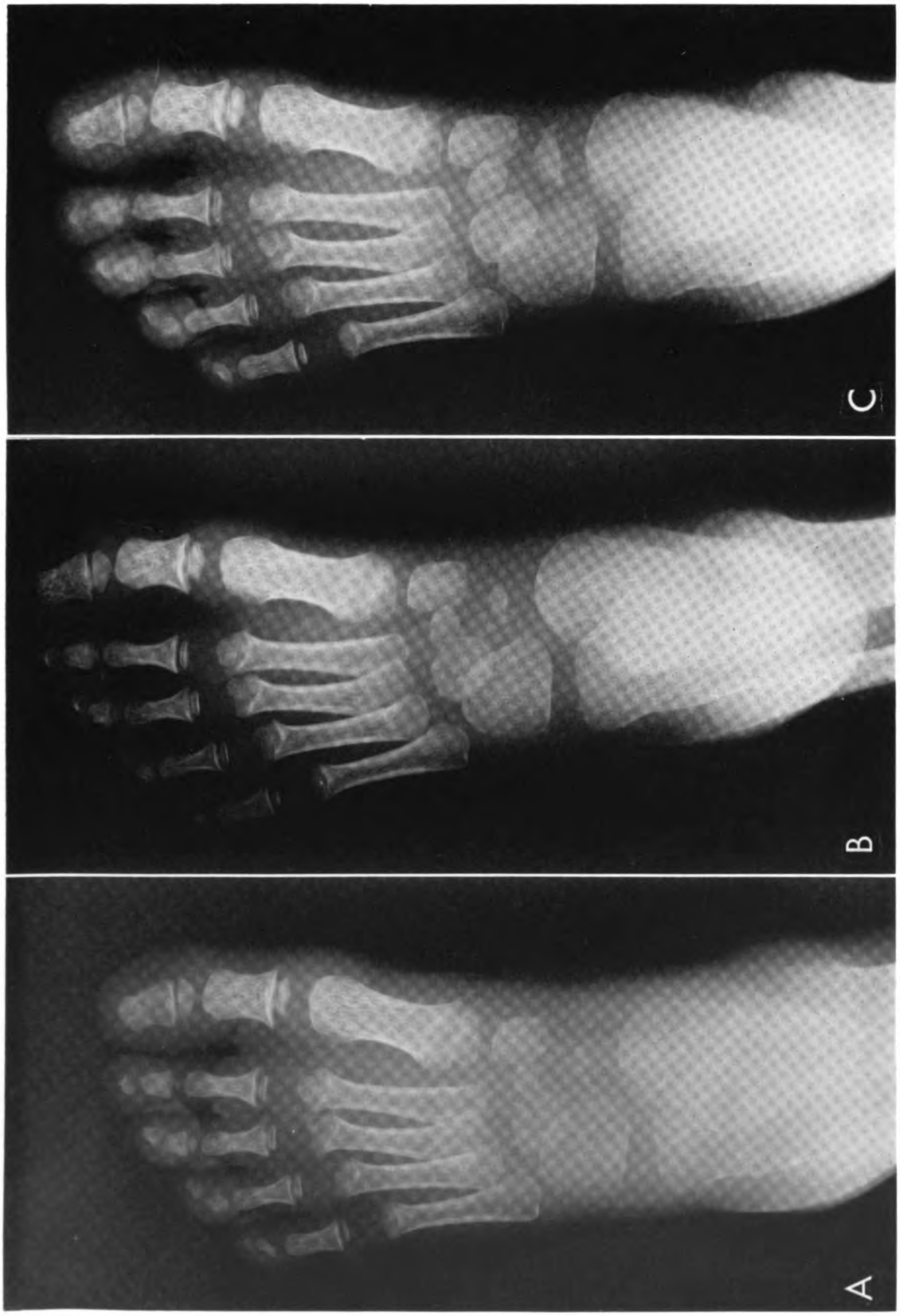
Figure 18 shows the range of the maturity indicators of the calcaneal epiphysis at age ten years, and Figure 19 illustrates the rate of development of a navicular which has somewhat delayed onset of ossification.

Our agreement in rankings, although not perfect, seems to indicate that the contours of these developing nodules displayed typical maturity indicator series. The largest bunches of films did appear centrally although we did not find "bell-shaped" distributions. It should be mentioned that standard Plates 15 to 30 include films of both boys and girls.

The single standard in this atlas, therefore, if our reasoning has been correct, if our method of locating each modal film has been trustworthy, and if our further reduction of the original plates for each sex to a single set of plates has been achieved with minimum smoothing, depicts the moderate rate of foot development as attained by the children in our Research Series.

Figure 18. Range of development of the calcaneal epiphysis at age ten years. These three films were selected from the ranked array of the films of 100 Research Series boys who were exactly ten years old. The ranking was based upon the osseous developmental levels of their calcaneal epiphyses.

The upper picture is that of the eighth foot in the array. This epiphysis contained a small compound nodule, with its longest axis indicated. The middle picture is that of a boy in the modal group. His epiphysis has nearly attained three-fourths of its superior-inferior extent. The lower picture is the view of the 100th foot in the array or that of the most advanced calcaneal epiphysis. Epiphyseal-diaphyseal fusion has begun.



A. 53 months B. 55 months C. 61 months

Figure 19. Development of the navicular. Within a period of eight months the navicular, which was delayed in onset of ossification, has developed very rapidly. From "Nutrition and Chemical Development in Childhood," Vol. II,[36] pages 649, 658 and 696.

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PART II

THE STANDARD OF REFERENCE

by

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Attributes of a Standard Plate and a Standard of Reference

THE SKELETAL AGE (male) and skeletal age (female) at the top of each page in the following section represents an average of the standardized bone ages in the Tables. The several bone ages, the two skeletal ages, and the halftone copy of a film together serve as a standard of reference plate.

In human toes, the middle and distal phalanges have a variable number of bone growth centers. Accordingly, we did not include any middle phalanx or the distal phalanx of the fifth toe in routine skeletal age assessment. We selectively include the distal phalanges of the second, third and fourth toes when they have an epiphysis and diaphysis, that is, have the regularly occurring parts of a short bone.

The bone ages which we use routinely for summation of the child's skeletal age (foot) are; those for the distal ends of the tibia and fibula, the tarsals, metatarsals, proximal phalanges, and distal phalanx of the great toe. See Chapter VII of Part I on *Design of the Standard of Reference* and pages seven to eleven of the knee atlas[3] for a description of our method of assigning bone ages to standard plates.

The descriptions of the selected maturity indicators in this section may duplicate some of the descriptions of each bone in Part III. However, most of the descriptions have been closely related to the halftones rather than to the tracings of individual bones in order to identify the direction and rate of spread of the ossification process as it fills in the changing bony outlines of adjacent bones during the interval between two plates.

The reader may select his own series of maturity indicators from those in Parts II and III or other indicators which are visible in the standard plates. He need only remember that the bone ages which accompany the standard plates have been chronologically scaled. Thus each two successive maturity indicators have the same developmental rate, that is, a moderate rate.

In the plate descriptions, we begin to omit tables of individual bone ages as soon as all bones in a standard plate can be assigned the same age equivalent. Then one continues to assess the age equivalent of each bone of the child's foot according to the skeletal age in the plate appropriate for its sex. The selected maturity indicators with the older standard plates are often paired markings, that is, adjacent markings belonging to a single joint. These are cardinal maturity indicators of individual bones, and they show when the single elements of joints display similar contours. Thus the beginner may wish to identify cardinal maturity indicators by tracing the development of a compound joint backward from Plate 30 to its earliest forerunner markings on the individual bones which constitute the joint.

Every maturity indicator must be related to an age equivalent in order to be meaningful as a unit in a scale for assessing the child's rate of bone calcification. The (pairs of) bone ages are thus always inseparable from the bones in the standard plates. The child's own age will be included when one is judging its rate of skeletal maturation.

INDIVIDUAL BONE AGES

This was the film of a boy with a fetal age of 40 weeks. Since in the later fetal months the foot of the female infant begins to mature more rapidly than that of the male infant on the same developmental schedule, the female foot will be slightly more advanced at birth. Accordingly, the skeletal age assigned to each bone in this plate is 40 weeks for boys and 38 weeks for girls.

SELECTED MATURITY INDICATORS

Hindfoot

Tibia and fibula, lateral view: The metaphyses flare slightly; the transverse diameters of their margins are greater than the transverse diameters of the diaphyses above them. Both metaphyses are smooth and flat. Both epiphyses are entirely cartilaginous. See Plates 4 and 7 for the location of the initial ossification centers.

Talus, lateral view: The shadow of the talus resembles a stubby peanut with its longest axis essentially anteroposterior. The margin shows four parts; flattened upper and lower, and rounded anterior and posterior margins.

Calcaneus, lateral view: The silhouette is pear-shaped with its greatest vertical dimension in the posterior part. The longest axis of the nodule is essentially horizontal. The shadow shows four parts; flattened dorsal and plantar, and rounded anterior and posterior margins. There is a slight indentation centrally in the dorsal margin. The posterior margin may also be referred to as the metaphysis since an epiphysis will cover it later. See Plates 19 to 27.

Midfoot

Cuboid, both views: Three or four nodules form a rounded cluster in its bone growth center. This is an example of compound onset of ossification as frequently seen in the tarsals and epiphyses of the foot. We are reserving the term *disseminated calcification* for the irregular spicule formation such as is seen in the bases of the four lateral metatarsals which give them, at a specific developmental stage, a fuzzy appearance in the radiograph.

The initial cuboid ossification center is aligned with the long axis of the calcaneus. If this axis is projected forward, it will pass approximately through the center of the cluster.

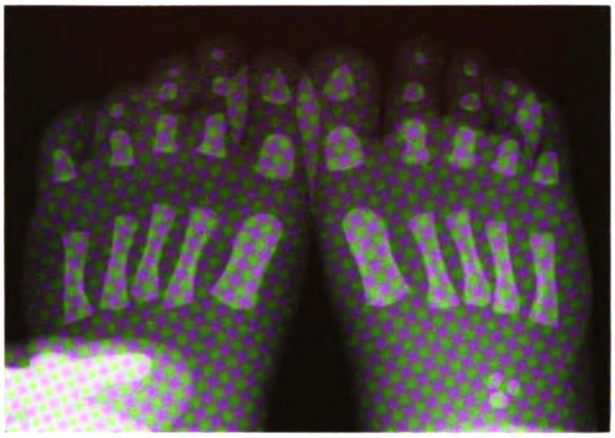
Forefoot

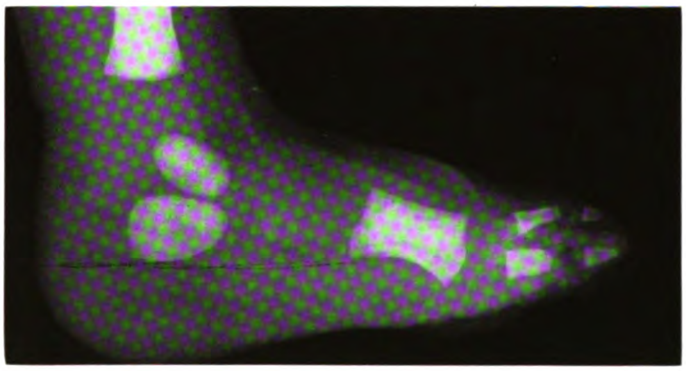
Metatarsals, dorsoplantar view: The epiphysis and metaphysis of the first metatarsal are in its proximal end; those of the four lateral metatarsals are distal. The five epiphyses are as yet entirely cartilaginous. The five metaphyses are becoming flattened, and tend to have sharp medial and lateral osseous corners.

The distal end of the first metatarsal has a much more rounded margin than the proximal ends of the four lateral metatarsals. The bases of the four lateral metatarsals do not overlap as they do later when the bony contours of the tarsometatarsal joints become visible in the film.

All five diaphyses show mid-shaft constriction, that is, osseous modeling.

Phalanges, dorsoplantar view: The shadows of the regularly-occurring diaphyses are now conical. All of the epiphyses, at the proximal ends of these phalanges, are entirely cartilaginous. The metaphyses are flattened. The proximal phalanges are slightly constricted, that is, modeled at mid-shaft. The modeling is most distinct in the second and third toes.





INDIVIDUAL BONE AGES

Bone	*Male* (*Weeks*)	*Female*	*Bone*	*Male* (*Weeks*)	*Female*
Distal end of tibia	5	3	Metatarsal I	5	3
Distal end of fibula	5	3	Metatarsal II	5	3
Talus	5	3	Metatarsal III	5	3
Calcaneus	5	3	Metatarsal IV	5	3
			Metatarsal V	5	3
Cuboid	5	3	Proximal phalanx I	5	3
Lateral cuneiform	*	*	Proximal phalanx II	5	3
Medial cuneiform	*	*	Proximal phalanx III	5	3
Intermediate cuneiform	*	*	Proximal phalanx IV	5	3
Navicular	*	*	Proximal phalanx V	5	3
* Entirely cartilaginous			Distal phalanx I	5	3

SELECTED MATURITY INDICATORS

Hindfoot

Tibia and fibula, lateral view: The metaphyses flare more posteriorly than anteriorly; they now project backward above the talus and the larger portion of the calcaneus.

Neck of the talus, lateral view: The upper and lower margins of the talus are beginning to appear indented. These two indentations demarcate the neck of the talus. The upper indentation separates the articular (trochlear) portion of the dorsal margin from the non-articular (free) portion. The indentation on the plantar margin separates the anterior and posterior articular facets of the (upper surface of) the talocalcaneal joint.

Position of the sinus tarsi, lateral view: On the dorsal margin of the calcaneus centrally, the indentation has become wide and shallow. This indentation, the calcaneal groove, and the indentation on the talus directly above it designate the position of the sinus tarsi.

Lowest bony point of the heel on the calcaneus, lateral view: A tubercle has appeared at the junction of the metaphysis and the plantar margin. The plantar margin is quite flat anterior to the tubercle.

Midfoot

Coalescence of the cuboid nodules, both views: The cluster of nodules seen in Plate 1 has been replaced by a single round nodule with a smooth circumference. The margins are beginning to form. The posterior margin facing the calcaneus is the most distinct and is beginning to be flattened. In the lateral view the horizontal diameter of the nodule is slightly greater than its vertical diameter.

Forefoot

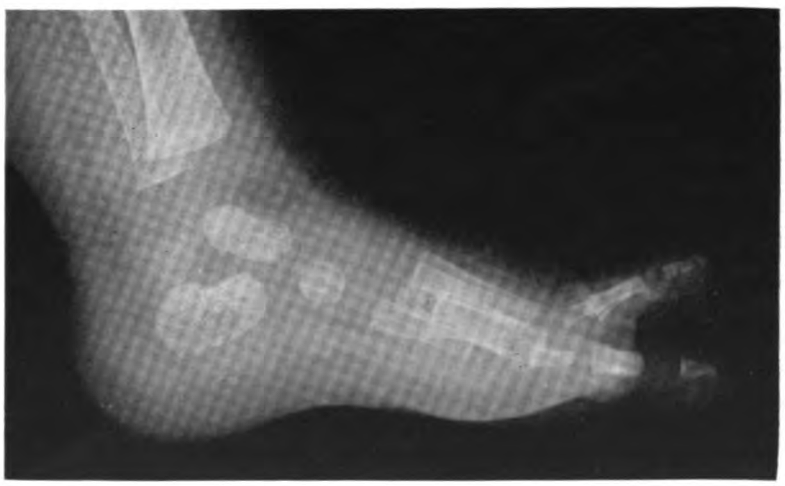
Differentiation of metatarsals, dorsoplantar view: The shafts of the four lateral metatarsals form a cluster. Both ends of all four bones show increased flaring. All metaphyses remain flat.

The mid-shaft modeling of metatarsal I increased; its metaphysis is slightly flared and its distal end is club-shaped.

Metatarsal II has become longer than the other four metatarsals, and it will remain longer during growth. Its proximal end is rounded.

Modeling of phalanges, dorsoplantar view: The five proximal phalanges and the distal phalanx of the great toe have distinct mid-shaft constriction. All metaphyses remain flat. The diaphyses of the distal phalanges of toes two, three, and four are tiny conical nodules, that is, they have the characteristic phalangeal shape.

MALE, SKELETAL AGE, 5 WEEKS POSTNATAL
FEMALE, SKELETAL AGE, 3 WEEKS POSTNATAL



INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female*	*Bone*	*Male* (*Months*)	*Female*
Distal end of tibia	3	2.5	Metatarsal I	3	2.5
Distal end of fibula	3	2.5	Metatarsal II	3	2.5
Talus	3	2.5	Metatarsal III	3	2.5
Calcaneus	3	2.5	Metatarsal IV	3	2.5
			Metatarsal V	3	2.5
Cuboid	3	2.5	Proximal phalanx I	3	2.5
Lateral cuneiform	3	2.5	Proximal phalanx II	3	2.5
Medial cuneiform	*	*	Proximal phalanx III	3	2.5
Intermediate cuneiform	*	*	Proximal phalanx IV	3	2.5
Navicular	*	*	Proximal phalanx V	3	2.5
* Entirely cartilaginous			Distal phalanx I	3	2.5

SELECTED MATURITY INDICATORS

Hindfoot

Talus, lateral view: The indentation on the upper margin has become a shallow excavation and directly below it, beneath the margin of the excavation, a dense white line is becoming visible. Osseous modeling is in process here. This concavity marks off the extent of the excursion of the tibia forward upon the talus. The indentation on the lower margin is now distinct. The neck of the talus and its articular and non-articular portions can be identified hereafter.

Calcaneus, lateral view: The anterior margin has begun to appear centrally flattened; this is the first indication that the calcaneus shapes reciprocally with the cuboid. The dorsal margin has become distinctly more concave, and directly below the concavity the plantar margin is flattened in similar dimension. Posteriorly, a thick strip of increased density has appeared beneath the metaphysis. The tubercle marking the boundary between the metaphysis and the plantar margin is now distinct.

Midfoot

Cuboid, lateral view: Its upper margin is beginning to flatten. The reciprocal flattening of the cuboid and calcaneus is the forerunner indicator of the osseous center of the calcaneocuboid joint.

Lateral cuneiform, both views: The bone reached the beginning of its osseous stage between Plates 2 and 3. The ossification center is now a round nodule with a smooth circumference. The nodule lies farther from the sole of the foot than does the cuboid. Its distal margin is aligned with the distal margin of the cuboid.

Forefoot

Metatarsals, dorsoplantar view: The proximal end of metatarsal II now shows two flat margins with an obtuse angle at their junction.

Phalanges, dorsoplantar view: The distal phalanges of the second, third, and fourth toes are distinctly conical, that is, they resemble the distal phalanx of the great toe without mid-shaft modeling as yet.

INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female* (*Months*)	*Bone*	*Male* (*Months*)	*Female* (*Months*)
Disal end of tibia	4	3.2	Metatarsal I	4	3.2
Distal end of fibula	4	3.2	Metatarsal II	4	3.2
Talus	4	3.2	Metatarsal III	4	3.2
Calcaneus	4	3.2	Metatarsal IV	4	3.2
			Metatarsal V	4	3.2
Cuboid	4	3.2	Proximal phalanx I	4	3.2
Lateral cuneiform	3.5	2.8	Proximal phalanx II	4	3.2
Medial cuneiform	*	*	Proximal phalanx III	4	3.2
Intermediate cuneiform	*	*	Proximal phalanx IV	4	3.2
Navicular	*	*	Proximal phalanx V	4	3.2
* Entirely cartilaginous			Distal phalanx I	4	3.2

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: The epiphyseal bone growth center contains a single, small, rounded nodule. It is aligned with the median plane of the tibial shaft. Since the metaphysis flares more posteriorly, the nodule is slightly nearer the front of the metaphysis than its posterior edge.

Talus, lateral view: A faint line of increased density is beginning to curve upward on the neck of the talus behind the indentation on the lower margin. The increased density of the posterior, sub-trochlear portion of the talus, barely visible in Plate 3, is now clearly shown.

Calcaneus, lateral view: At the junction of the metaphysis and plantar margin, the lowest bony point of the heel is prominent. This process will be covered by the epiphysis later. See Plates 26 to 30.

The band of increased density inside the metaphysis is thick and distinct.

The bone is modeled, that is, appears constricted below the sinus tarsi. Posterior to this modeling, the first strands of its characteristic oblique trabecular pattern are visible in the original film.

Midfoot

Cuboid, both views: The circumference of the silhouette displays its initial dorsal, anterior, plantar, and posterior sub-divisions. The margin adjacent to the lateral cuneiform is flattened.

Lateral cuneiform, dorsoplantar view: The cortex remains undifferentiated, that is, it has none of the initial sub-divisions.

Forefoot

Individual shaping of metatarsals, dorsoplantar view: The silhouettes of the first metatarsal and the proximal phalanges have been similar. Now there is a protuberance on the lateral side of the distal end of the first metatarsal.

Localized shaping of the base of metatarsal II, described initially with Plate 3, has become distinct.

Phalanges, dorsoplantar view: Osseous modeling is seen extensively along each shaft.

MALE, SKELETAL AGE, 4 MONTHS
FEMALE, SKELETAL AGE, 3.2 MONTHS

INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female*	*Bone*	*Male* (*Months*)	*Female*
Distal end of tibia	6	5	Metatarsal I	6	5
Distal end of fibula	6	5	Metatarsal II	6	5
Talus	6	5	Metatarsal III	6	5
Calcaneus	6	5	Metatarsal IV	6	5
			Metatarsal V	6	5
Cuboid	6	5	Proximal phalanx I	6	5
Lateral cuneiform	6	5	Proximal phalanx II	6	5
Medial cuneiform	*	*	Proximal phalanx III	6	5
Intermediate cuneiform	*	*	Proximal phalanx IV	6	5
Navicular	*	*	Proximal phalanx V	6	5
* Entirely cartilaginous			Distal phalanx I	6	5

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: It is established that the initial ossification center of the tibial epiphysis, from which the upper ankle-joint surface is derived, forms in the median plane of the tibia. The nodule is directly above the trochlea (lower ankle joint surface) where the initial thickening of the talus has occurred.

Talus, lateral view: Behind the indentation on its lower margin the thin white outline which began to be visible in Plate 4 has become distinct.

Calcaneus, lateral view: On the upper surface, two white outlines indicate the lateral and medial margins of the calcaneal groove. The trabecular pattern within the calcaneus posteriorly is visible in the halftone as well as in the original film.

Midfoot

Cuboid and lateral cuneiform articulation, dorsoplantar view: The margin of the cuboid is distinctly flattened, thereby indicating the positioning of the joint between the cuboid and lateral cuneiform.

Forefoot

Metatarsals, dorsoplantar view: The proximal ends of the four lateral metatarsals form an arc which is convex distally. This is the first indication that the convexity of the tarsometatarsal joints is centered between metatarsals III and IV.

The proximal end of metatarsal II is blunt and not so sharply "chiseled" as it was in Plates 3 and 4. This may be a matter of positioning or individual difference.

Phalanges, dorsoplantar view: The regularly-occurring phalanges each show increased constriction across the center of the shaft, and all have lengthened in similar amount. From this view, because the toes are flexed, the metaphyses appear less flattened than previously. From the lateral view the previous flattening is confirmed.

PLATE 5

MALE, SKELETAL AGE, 6 MONTHS
FEMALE, SKELETAL AGE, 5 MONTHS

INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female* (*Months*)	*Bone*	*Male* (*Months*)	*Female* (*Months*)
Distal end of tibia	7	6	Metatarsal I	7	6
Distal end of fibula	7	6	Metatarsal II	7	6
Talus	7	6	Metatarsal III	7	6
Calcaneus	7	6	Metatarsal IV	7	6
			Metatarsal V	7	6
Cuboid	7	6	Proximal phalanx I	7	6
Lateral cuneiform	7	6	Proximal phalanx II	7	6
Medial cuneiform	*	*	Proximal phalanx III	7	6
Intermediate cuneiform	*	*	Proximal phalanx IV	7	6
Navicular	*	*	Proximal phalanx V	7	6
			Distal phalanx I	7	6

* Entirely cartilaginous

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: The epiphyseal nodule is oval; its longest axis is transverse. Reciprocal shaping of the epiphysis and metaphysis has begun centrally.

Talus, lateral view: The bone has elongated. On the dorsal surface the medial and lateral margins of the indentation can be traced. The neck of the bone is established.

Calcaneus, lateral view: The bone has also elongated. Behind the calcaneal groove, the roundness of the upper surface is beginning to be reduced.

Midfoot

Cuboid and lateral cuneiform, both views: Both bones have elongated. Reciprocal shaping of the adjacent parts of their margins has begun, thereby designating in each bone the location of the cuboid-cuneiform joint. If the long axis of the cuneiform is projected forward, it will pass approximately through the apex of the arc formed by the proximal ends of the four lateral metatarsals. Accordingly, the position of this cuneiform marks the center of the tarsometatarsal joints.

Forefoot

Metatarsals, dorsoplantar view: Excepting metatarsal I, it is the non-epiphyseal end of each metatarsal which has hereafter the greatest (osseous) transverse dimension. Thus their proximal ends are their widest ends.

Phalanges, dorsoplantar view: It is also the proximal end of each phalanx—at present its metaphysis—which has the greatest transverse dimension.

MALE, SKELETAL AGE, 7 MONTHS
FEMALE, SKELETAL AGE, 6 MONTHS

INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female*	*Bone*	*Male* (*Months*)	*Female*
Distal end of tibia	11	9	Metatarsal I	11	9
Distal end of fibula	12	9	Metatarsal II	11	9
Talus	11	9	Metatarsal III	11	9
Calcaneus	11	9	Metatarsal IV	11	9
			Metatarsal V	11	9
Cuboid	11	9	Proximal phalanx I	11	9
Lateral cuneiform	11	9	Proximal phalanx II	11	9
Medial cuneiform	*	*	Proximal phalanx III	11	9
Intermediate cuneiform	*	*	Proximal phalanx IV	11	9
Navicular	*	*	Proximal phalanx V	11	9
			Distal phalanx I	11	9

* Entirely cartilaginous

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: The anteroposterior diameter of the epiphysis is approximately one-half that of the metaphysis. The nodule is rounded anteriorly and pointed posteriorly.

The strip of lesser density between the epiphysis and metaphysis is narrow and uniform; the growth cartilage plate has attained its characteristic thickness centrally.

Fibula, lateral view: Ossification of the epiphysis has begun. As yet the nodule is thin and its circumference is indistinct.

Talus, lateral view: The two portions of the bone, as marked off by the neck, differ distinctly in their density. For several standards the trochlear portion will remain quite globular.

Calcaneus, lateral view: The trabecular pattern in the posterior portion is behind and below the ankle joint; it sweeps obliquely toward the metaphysis. The posterior, talar articular facet on the upper margin no longer appears rounded.

The anterior margin, facing the cuboid, is beginning to appear flattened.

Midfoot

Cuboid, both views: Its entire cuneiform margin is flattened.

Lateral cuneiform, both views: The lateral, medial, and dorsal margins display flattening.

Forefoot

Metatarsals, dorsoplantar view: The proximal ends of the four lateral metatarsals are bulbous and their adjacent sides have begun to shape reciprocally.

Phalanges, dorsoplantar view: The regularly occurring shafts have increased more in length than in their transverse dimension. Note the absence of ossification in the distal phalanx of the fifth toe, and the diaphyseal "nubbins" in the middle phalanges. These phalanges, as well as those in the preceding plates, illustrate variations commonly found in number, ossification sequence, and shape of their ossification centers.

PLATE 7

MALE, SKELETAL AGE, 11 MONTHS
FEMALE, SKELETAL AGE, 9 MONTHS

INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female*	*Bone*	*Male* (*Months*)	*Female*
Distal end of tibia	12	10	Metatarsal I	12	10
Distal end of fibula	12	9	Metatarsal II	12	10
Talus	12	10	Metatarsal III	12	10
Calcaneus	12	10	Metatarsal IV	12	10
			Metatarsal V	12	10
Cuboid	12	10	Proximal phalanx I	12	10
Lateral cuneiform	12	10	Proximal phalanx II	12	10
Medial cuneiform	*	*	Proximal phalanx III	12	10
Intermediate cuneiform	*	*	Proximal phalanx IV	12	10
Navicular	*	*	Proximal phalanx V	12	10
			Distal phalanx I	12	10

* Entirely cartilaginous

This film was selected after detailed matching with the original modal film to show the contours of the maturity indicators at this stage from the oblique view of the foot rather than the direct lateral view. This is the film of a boy. Plate 7 is the film of a girl at a slightly earlier stage of development. Since most of the maturity indicators in this plate show only accentuation of the indicators described with Plate 7, this plate emphasizes the gradual increase in skeletal age difference between the sexes.

SELECTED MATURITY INDICATORS

Hindfoot

Ossification of the upper and lower portions of the ankle joint, lateral view: The upper ankle joint surface is derived from the tibial and fibular epiphyses; the fibular epiphysis furnishes the lateral wall.

The lower ankle joint surface, trochlea of the talus, extends forward to the upper groove on the neck of the bone; here the groove is distinctly modeled.

Calcaneus, lateral view: The following markings and processes can be identified as easily from the oblique view of the foot as from the direct lateral view; angle of demarcation at the junction of the dorsal and anterior margins, lowest bony point of the heel, flattening of the posterior talar articular facet, and the oblique sweep of the trabecular pattern in the posterior part of the bone.

Midfoot

Cuboid and lateral cuneiform, both views: In Plate 7, the flattening of the dorsal margin of each bone was visible. Accordingly, since the flattening is visible here as well, the difference in position during filming does not obscure this maturity indicator.

Forefoot

Metatarsals and phalanges, both views: The relatively greater increase in shaft length, in proportion to increase in transverse dimension, is distinct. The shafts now appear slender.

The margins of the proximal ends of the four lateral metatarsals have become somewhat thickened, and those of II, III, and IV are somewhat flattened. This blunting and thickening were immediate precursors of disseminated calification of these margins, as shown by the complete film series of this boy as well as series of other children. In contrast to disseminated calcification in the knee,[3] thickening rather than thinning of the margin has occurred.

MALE, SKELETAL AGE, 12 MONTHS
FEMALE, SKELETAL AGE, 10 MONTHS

INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female*	*Bone*	*Male* (*Months*)	*Female*
Distal end of tibia	18	15	Metatarsal I	18	14
Distal end of fibula	18	14	Metatarsal II	18	14
Talus	18	15	Metatarsal III	18	14
Calcaneus	18	15	Metatarsal IV	18	14
			Metatarsal V	18	14
Cuboid	18	15	Proximal phalanx I	18	14
Lateral cuneiform	18	15	Proximal phalanx II	18	14
Medial cuneiform	*	*	Proximal phalanx III	18	14
Intermediate cuneiform	*	*	Proximal phalanx IV	18	14
Navicular	*	*	Proximal phalanx V	18	14
* Entirely cartilaginous			Distal phalanx I	18	14

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: The thin, sharply-etched line along the central portion of the inner bone margin denotes the beginning of the terminal plate.

The outer bone margin has become concave. Notice that this initial articular facet (concavity) which is in the upper joint surface of the ankle is in the same median plane of the shaft as was the initial epiphyseal nodule (Plate 4).

Fibula, lateral view: The longest axis of the epiphysis is transverse. Its inner bone margin is beginning to flatten, that is, shape reciprocally with the metaphysis.

Talus and calcaneus, lateral view: The posterior portions of these two bones are similarly dense; these are their weight-receiving portions.

The entire anterior facet of the talus on its plantar margin is flattened.

Calcaneus, lateral view: Osseous modeling of the sustentaculum tali is indicated by a localized area of increased density below the concavity in the upper surface.

Midfoot

Cuboid and lateral cuneiform, dorsoplantar view: In the center of the cuboid-cuneiform joint, the adjacent margins of the two bones have begun to overlap.

Forefoot

Onset of ossification in phalangeal epiphyses, dorsoplantar view: Onset of ossification occurs close to the metaphyses; the strips of lesser density are narrow.

Ossification of epiphyses II, III, and IV has begun. In the original film of this plate, the tiny epiphyseal nodules are distinct, but are super-imposed (by positioning during filming) upon the metaphysis.

The distal epiphysis of the great toe also contains an ossification center; its longest axis is transverse.

MALE, SKELETAL AGE, 18 MONTHS
FEMALE, SKELETAL AGE, 14 MONTHS

INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female* (*Months*)	*Bone*	*Male* (*Months*)	*Female* (*Months*)
Distal end of tibia	24	18	Metatarsal I	30	21
Distal end of fibula	24	17	Metatarsal II	24	18
Talus	24	18	Metatarsal III	24	18
Calcaneus	24	18	Metatarsal IV	24	18
			Metatarsal V	24	18
Cuboid	24	18	Proximal phalanx I	24	18
Lateral cuneiform	24	18	Proximal phalanx II	24	18
Medial cuneiform	24	18	Proximal phalanx III	24	18
Intermediate cuneiform	*	*	Proximal phalanx IV	24	18
Navicular	*	*	Proximal phalanx V	23	16
* Entirely cartilaginous			Distal phalanx I	28	19

SELECTED MATURITY INDICATORS

Hindfoot

Tibial epiphysis, lateral view: The articular facet in the outer bone margin is concave and shallow. Since the upper ankle joint surface is ultimately concave (Plates 27 to 30), the indentation which has developed establishes the structural center of this joint surface.

Fibula, lateral view: The narrow strip of lesser density between the epiphysis and metaphysis is quite uniform. The growth cartilage plate within it has presumably attained that thickness centrally which will characterize it during childhood.

Talus, lateral view: With Plates 2 and 5, mention was made of a notch and a thin white outline which were forming centrally on the lower surface. A blunt osseous process has begun to form behind the notch. When the process is fully ossified, it will be the posteromedial wall of the groove of the talus (upper part of the sinus tarsi).

Calcaneus, lateral view: A trabecular band is beginning to extend forward from the calcifying sustentaculum tali toward the cuboid margin of the bone. This band is in the same plane as the structural center of the midtarsal joint and thus becomes an important forerunner indicator of the center.

Midfoot

Medial cuneiform, dorsoplantar view: Its ossification center, as yet compound, is beginning to show its long axis. If this axis were projected forward, it would coincide with the central axis of the great toe.

Forefoot

Metatarsals, dorsoplantar view: The epiphysis of metatarsal I reached the osseous stage of its development between Plates 9 and 10. The longest axis of the oval nodule is transverse. The proximal ends of metatarsals II, III, and IV are slightly roughened. This evidence of disseminated calcification is present in varying degrees at this stage of development. This is the only articulation in the extremities where we have observed disseminated calcification as a natural process on a sub-articular surface.

Phalanges, dorsoplantar view: All regularly occurring epiphyses in the phalanges have reached the osseous stage of development. In rapid sequence; each nodule shows its longest axis, the growth cartilage plate attains its characteristic thickness centrally, and the terminal plate begins to calcify. Here, for example, the distal epiphysis of the great toe has begun to attain the third of these maturity indicators; in the original film the terminal plate, a thin white outline across the center of the inner bone margin, shows more clearly than in this halftone. In contrast the proximal epiphysis of the great toe shows compound ossification, its initial maturity indicator.

PLATE 10

MALE, SKELETAL AGE, 24 MONTHS
FEMALE, SKELETAL AGE, 18 MONTHS

INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female*	*Bone*	*Male* (*Months*)	*Female*
Distal end of tibia	30	23	Metatarsal I	28	21
Distal end of fibula	30	23	Metatarsal II	30	23
Talus	30	23	Metatarsal III	30	23
Calcaneus	30	23	Metatarsal IV	30	23
			Metatarsal V	30	23
Cuboid	30	23	Proximal phalanx I	25	19
Lateral cuneiform	30	23	Proximal phalanx II	30	23
Medial cuneiform	24	18	Proximal phalanx III	30	23
Intermediate cuneiform	30	23	Proximal phalanx IV	30	23
Navicular	*	*	Proximal phalanx V	28	21
* Entirely cartilaginous			Distal phalanx I	30	23

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: The outer bone margin of the epiphysis shows two boundaries. The distal, slightly lower boundary is that of the medial surface of the epiphysis.

The terminal plate outlines the center of the inner bone margin distinctly.

The epiphysis is relatively thick anteriorly and pointed posteriorly.

Fibula, lateral view: The outer bone margin of the epiphysis is beveled posteriorly. The growth cartilage plate has become quite uniform. The terminal plate is the most distinct posteriorly.

Talus, lateral view: By Plate 10, an osseous process had begun to project downward behind the lower groove on the neck of the bone. Here the outline of the process is triangular.

Calcaneus, lateral view: The metaphysis appears to flare posteriorly because the dorsal and plantar margins of the posterior portion of the bone are modeled (indented).

A small "bump" has appeared on the plantar margin, about halfway between the tubercle and the anterior margin. A groove will form immediately distal to it. See Plates 19 to 23.

Midfoot

Cuboid, dorsoplantar view: The posterior margin is flat. A thin white outline extends from it to the small beveled margin adjacent to the talus.

Intermediate cuneiform, dorsoplantar view. Its ossification has recently begun. The thin nodule is aligned with the medial side of the shaft of the second metatarsal.

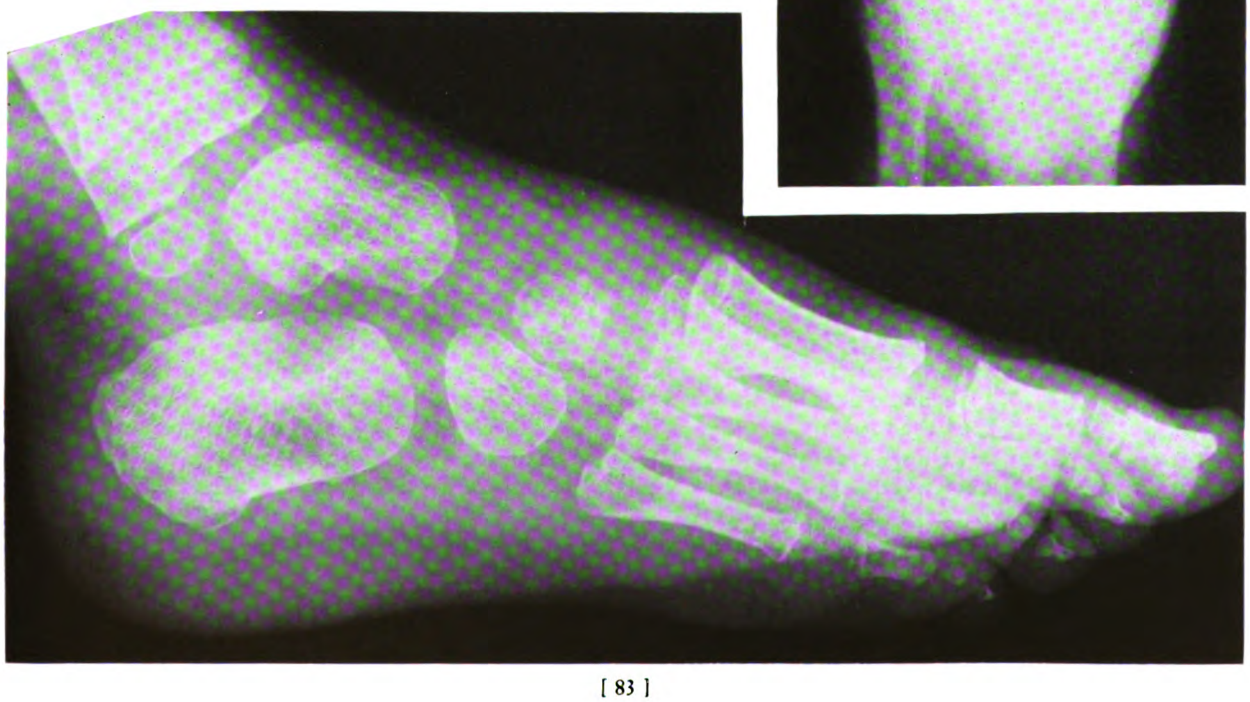
Forefoot

Metatarsals, dorsoplantar view: In the original film, the epiphysis of the second metatarsal contains a few osseous particles; due to the photographic angle, they appear to be superimposed upon the metaphysis.

Although the ossification center in the epiphysis of metatarsal I remains compound, the strip of lesser density has become quite uniform. Presumably this growth cartilage plate has attained its characteristic thickness centrally. The osseous nodules are arrayed along the longest axis of the epiphysis, a transverse axis.

Phalanges, dorsoplantar view: The thickness of each growth cartilage plate has been established centrally. The terminal plates are fairly distinct in (the epiphyses of) proximal phalanges II, III, and IV. These epiphyses are disk-shaped. The distal epiphysis of the great toe is triangular.

MALE, SKELETAL AGE, 30 MONTHS
FEMALE, SKELETAL AGE, 23 MONTHS



INDIVIDUAL BONE AGES

Bone	*Male* (*Months*)	*Female*	*Bone*	*Male* (*Months*)	*Female*
Distal end of tibia	36	28	Metatarsal I	36	28
Distal end of fibula	36	28	Metatarsal II	36	28
Talus	36	28	Metatarsal III	36	28
Calcaneus	36	28	Metatarsal IV	36	28
			Metatarsal V	36	28
Cuboid	36	28	Proximal phalanx I	29	22
Lateral cuneiform	36	28	Proximal phalanx II	36	28
Medial cuneiform	36	28	Proximal phalanx III	36	28
Intermediate cuneiform	30	23	Proximal phalanx IV	36	28
Navicular	*	*	Proximal phalanx V	28	21
* Entirely cartilaginous			Distal phalanx I	36	28

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: The calcification of the pointed posterior "side" of the epiphysis is slightly disseminated. Anteriorly the epiphysis and diaphysis are so nearly equal in their tranverse dimensions that the white outline of the terminal plate is beginning to curve downward over the front of the epiphysis toward the trochlea of the talus.

Talus, lateral view: The degree of flatness of the articular facets on its plantar surface shown here will be maintained until the (final) ossification of each sub-articular margin of the joint begins.

The area of the anterior half of the bone is greater than the area of the posterior half. Two forms of taluses were seen in our Research Series films; the rounded form as seen here, and the elongated form as seen in Plates 14 and 15. At this stage of development, the rounded form has a flared anterior surface. Consequently, the osseous corner at the junction of its dorsal, medial and anterior surfaces is sharp and prominent. The corresponding corner of an elongated talus will remain low and blunted.

Calcaneus, lateral view: The plantar surface is concave. A narrow trabecular band, extending forward from the metaphysis, outlines the concavity centrally. This trabecular modeling indicates that the ossification process has penetrated the cartilaginous cortex close to its plantar surface.

Midfoot

Cuboid, lateral view: A blunt osseous corner is forming at the junction of its calcaneal, medial, and upper surfaces.

Lateral and medial cuneiforms, dorsoplantar view: The anterior surface of the medial cuneiform is flattened. For several standards the anterior surfaces of the lateral cuneiform and cuboid have been shaping to the arc formed by the proximal ends of the metatarsals. Thus osseous differentiation of the tarsometatarsal joint has begun medially with this standard plate.

Forefoot

Metatarsals, dorsoplantar view: Ossification has begun in the epiphyses of metatarsals II, III, and IV. Due to position during filming, the nodules appear superimposed upon the metaphyses.

Phalanges, dorsoplantar view: The outer bone margins of the epiphyses of proximal phalanges II, III, and IV are concave. The center of each articular facet has thus become visible.

MALE, SKELETAL AGE, 36 MONTHS (3.0 YEARS)
FEMALE, SKELETAL AGE, 28 MONTHS (2.3 YEARS)

INDIVIDUAL BONE AGES

Bone	*Male* (*Years*)	*Female*	*Bone*	*Male* (*Years*)	*Female*
Distal end of the tibia	3.5	2.7	Metatarsal I	4.4	3.3
Distal end of the fibula	3.5	2.7	Metatarsal II	3.8	3.0
Talus	3.5	2.7	Metatarsal III	3.7	2.9
Calcaneus	3.5	2.7	Metatarsal IV	3.8	3.0
			Metatarsal V	3.8	3.0
Cuboid	3.5	2.7	Proximal phalanx I	4.4	3.3
Lateral cuneiform	3.5	2.7	Proximal phalanx II	3.8	3.0
Medial cuneiform	3.0	2.4	Proximal phalanx III	3.8	3.0
Intermediate cuneiform	3.5	2.7	Proximal phalanx IV	3.8	3.0
Navicular	3.5	2.7	Proximal phalanx V	4.4	3.3
			Distal phalanx I	4.4	3.3

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: The articular facet in the epiphysis is distinctly outlined and definitely concave. Although the facet is not as wide as the metaphysis, it is nearly as wide as the portion of the diaphysis immediately above the metaphysis. The fully-developed upper joint surface of the ankle is not as wide as the tibial shaft above the terminal line of the bone. See Plates 27 to 30.

Fibula, lateral view: The beveling of the epiphysis posteriorly has increased.

Talus, lateral view: A deep notch, the talar groove, divides its lower surface into two facets which are the anterior and posterior portions of the upper surface of the talocalcaneal joint.

The triangular process, first described with Plate 10, now forms the posterior boundary of the groove.

Calcaneus, lateral view: The anterior margin of the calcaneus is flattened.

The posterior talocalcaneal articular facet, on its upper surface, is also flattened.

Midfoot

Cuboid, both views: Localized increase in density under an articular margin forecasts reciprocal shaping of joint surfaces. Such increase in density has begun beneath the calcaneal surface of the cuboid.

The joint space between the cuboid and calcaneus is quite uniform.

Lateral cuneiform, dorsoplantar view: Its medial margin has become bipartite with a straight side and a beveled distal portion. The beveled facet is shaped according to the slope of the adjacent edge of metatarsal II.

Medial cuneiform, dorsoplantar view: Its long dimension is now becoming visible. When the central axis of the nodule is projected distally, it points to the center of the epiphysis of metatarsal II.

Intermediate cuneiform, dorsoplantar view: The nodule now presents flattened facets anteriorly and laterally.

Navicular, dorsoplantar view: Ossification of the nodule is in process. It is centered according to the long axis of the talus.

Forefoot

Compound onset of epiphyseal ossification has been described repeatedly with the last few plates. The fact that the adjacent (longer calcifying) bones have smooth circumferences should not mislead the beginner to assume that compound onset of ossification indicates "aberrant" bone growth centers.

MALE, SKELETAL AGE, 3.7 YEARS
FEMALE, SKELETAL AGE, 2.9 YEARS

INDIVIDUAL BONES AGES

Bone	*Male* (*Years*)	*Female* (*Years*)	*Bone*	*Male* (*Years*)	*Female* (*Years*)
Distal end of tibia	4.4	3.3	Metatarsal I	4.4	3.3
Distal end of fibula	4.4	3.3	Metatarsal II	4.4	3.3
Talus	4.4	3.3	Metatarsal III	4.0	3.0
Calcaneus	4.4	3.3	Metatarsal IV	4.2	3.2
			Metatarsal V	4.0	3.0
Cuboid	4.2	3.2	Proximal phalanx I	4.2	3.2
Lateral cuneiform	4.2	3.2	Proximal phalanx II	4.2	3.2
Medial cuneiform	4.4	3.3	Proximal phalanx III	4.2	3.2
Intermediate cuneiform	4.2	3.2	Proximal phalanx IV	4.2	3.2
Navicular	4.2	3.2	Proximal phalanx V	4.2	3.2
			Distal phalanx I	4.2	3.2

SELECTED MATURITY INDICATORS

Hindfoot

Fibula, lateral view: A soft transverse line of increased density is forming across the epiphysis. This line marks the upper margin of its malleolar fossa. The lateral malleolus projects below this marking.

Talus, lateral view: In Plate 13, the posterior surface of the trochlea has begun to appear flattened. Although the talus in this plate is more elongated than the bone in Plate 13, this trochlea also appears flattened.

Posterior talocalcaneal articulation, lateral view: Reciprocal shaping of the adjacent articular facets is in process. The joint space remains wide.

Midfoot

Cuboid, lateral view: A thin white line extends forward from the calcaneal surface of the bone. This marking is in the edge of the groove in which the tendon of the peroneus longus muscle glides.

Navicular, both views: The shape of the nodule is remarkably similar in each view. This was also true in Plate 13. Its posterior margin is quite flat.

Alignment of tarsal and metatarsal margins, dorsoplantar view: The distal row of tarsals has become sufficiently developed to see the alignment of some margins of bone pairs which form the several tarsal-metatarsal joints. These alignments are; (a) lateral sides of the medial cuneiform and epiphysis of metatarsal I, (b) medial sides of the intermediate cuneiform and base of metatarsal II, and (c) lateral side of the cuboid and central axis of metatarsal V.

Within the shadow of the lateral cuneiform, a thin curved line extends toward the medial side of metatarsal IV. This is one of the initial markings on the plantar surfaces of midfoot bones to become visible in a film.

Forefoot

Metatarsals, dorsoplantar view: The initial small nodules in the epiphyses of metatarsals III, IV and V have nearly coalesced. The epiphyses of metatarsals I and II show flattened articular facets. Accordingly, blunted angles of demarcation have begun to form between the facets and the sides of the epiphyses.

The epiphysis of metatarsal I tapers medially.

Phalanges, dorsoplantar view: Each growth cartilage plate has become narrow and centrally uniform.

The distal epiphysis of the great toe tapers laterally and is relatively thick medially.

MALE, SKELETAL AGE, 4.2 YEARS
FEMALE, SKELETAL AGE, 3.2 YEARS

INDIVIDUAL BONE AGES

Bone	*Male* (*Years*)	*Female*	*Bone*	*Male* (*Years*)	*Female*
Distal end of tibia	5.0	3.8	Metatarsal I	4.5	3.5
Distal end of fibula	5.0	3.8	Metatarsal II	5.0	3.8
Talus	5.0	3.8	Metatarsal III	4.5	3.5
Calcaneus	5.0	3.8	Metatarsal IV	4.8	3.6
			Metatarsal V	4.8	3.7
Cuboid	5.0	3.8	Proximal phalanx I	5.0	3.8
Lateral cuneiform	5.0	3.8	Proximal phalanx II	5.0	3.8
Medial cuneiform	5.0	3.8	Proximal phalanx III	5.0	3.8
Intermediate cuneiform	4.3	3.4	Proximal phalanx IV	5.0	3.8
Navicular	4.7	3.6	Proximal phalanx V	4.5	3.5
			Distal phalanx I	4.7	3.7

SELECTED MATURITY INDICATORS

Hindfoot

Ankle joint, lateral view: The lipping of the tibial epiphysis over the trochlea, begun in Plate 13, has become distinct.

Within the shadow of the epiphysis the densest outline along the articular facet marks its lateral side. The thin portion of bone below this outline is the ossified portion of the medial malleolus. Nearby, within the shadow of the fibular epiphysis, is the short transverse marking along the upper margin of the malleolar fossa.

Comparison of this plate with Plate 14 shows that the developmental flattening of this elongated trochlea has continued posteriorly.

Modeling of the sinus tarsi: In the talus, the upper posteromedial wall of the sinus tarsi is represented in a film by the triangular shadow behind the central notch in its lower margin. This process now projects toward the sustentaculum tali.

Hindfoot and Midfoot

Mid-tarsal joint, both views: In Plate 14, the posterior margin of the navicular showed initial flattening. This flattening is the forerunner indicator of the position of its articular facet. Plate 4 shows the corresponding indicator of the cuboid. The longest horizontal axis of the talus points toward the flattening on the navicular.

In the lateral view, the area of each of the two joint spaces has become quite uniform.

Midfoot and Forefoot

Further alignment of tarsals and metatarsals, dorsoplantar view: Reciprocal shaping of the adjacent articular margins of the metatarsals and tarsals has begun.

Initial maturity indicators of forefoot joints, dorsoplantar view: The distal margins of the epiphyses of metatarsals II, III, and IV were slightly flattened in Plate 14; here they are distinctly flattened.

The compound ossification in the epiphysis of metatarsal V has passed its peak; the nodules have begun to coalesce. The outer bone margin of the largest nodule is beginning to show the typical distal flattening.

The interphalangeal joint space in the great toe has been reduced.

MALE, SKELETAL AGE, 4.9 YEARS
FEMALE, SKELETAL AGE, 3.7 YEARS

INDIVIDUAL BONE AGES

Bone	*Male* (*Years*)	*Female*	*Bone*	*Male* (*Years*)	*Female*
Distal end of tibia	5.5	4.2	Metatarsal I	5.5	4.2
Distal end of fibula	5.5	4.2	Metatarsal II	5.5	4.2
Talus	5.5	4.2	Metatarsal III	5.5	4.2
Calcaneus	5.5	4.2	Metatarsal IV	5.5	4.2
			Metatarsal V	5.3	4.0
Cuboid	5.5	4.2	Proximal phalanx I	5.5	4.2
Lateral cuneiform	5.5	4.2	Proximal phalanx II	5.5	4.2
Medial cuneiform	5.5	4.2	Proximal phalanx III	5.5	4.2
Intermediate cuneiform	5.5	4.2	Proximal phalanx IV	5.5	4.2
Navicular	5.3	4.0	Proximal phalanx V	5.3	4.0
			Distal phalanx I	5.3	4.0

SELECTED MATURITY INDICATORS

This plate, like Plates 14, 15 and 19, have been made from one boy's film series. Plate 17 has been included to show the female foot at nearly the same maturity level. We shall make some comparisons of the same maturity indicators, at the slightly differing levels, in the two plates.

Hindfoot

Ankle joint, lateral view: The upper joint surface in the tibial epiphysis and the lower joint surface, the trochlea, are similarly curved. The medial malleolus can be easily identified as the portion of the epiphysis which projects below the upper articular facet.

Midfoot

Navicular, both views: Its posterior articular facet is barely indented; it is distinctly thickened. The lower, plantar half of the nodule, as in Plate 17, has a greater proximal-distal diameter than that of the dorsal half.

Cuboid, both views: The calcaneal surface of the cuboid now shows two distinct outlines. The posterior outline is the medial margin of the articular facet, and the more distal marking is in its lateral margin.

The short outline of greater density inside the plantar margin of the cuboid denotes the entrance of the groove for the tendon of the peroneus longus muscle.

Medial cuneiform, dorsoplantar view: There is a small notch in the anterior part of its lateral margin. In the same transverse plane, a small white marking of increased density is forming on the medial margin. This medial line marks the site for the insertion of the tibialis anterior muscle.

Forefoot

Epiphysis of metatarsal V, dorsoplantar view: The several osseous nodules previously described have coalesced. The only remnant of compound ossification is the small notch in the outer bone margin of the epiphysis.

Phalangeal articular facets, dorsoplantar view: The articular facets in the epiphyses of the proximal phalanges are distinctly concave and distinctly outlined. Each phalangeal facet is as wide as the adjacent metatarsal facet.

Beginning with Plate 14, the distal epiphysis of the great toe became distinctly thickened medially and pointed laterally; its inner bone margin is flat.

MALE, SKELETAL AGE, 5.5 YEARS
FEMALE, SKELETAL AGE, 4.2 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 6 years 0 months for boys and 4 years 6 months for girls.

SELECTED MATURITY INDICATORS

Plate 16 was made from the radiograph of a boy's foot; this plate from that of a girl's foot. Although the difference in skeletal age (foot) of the sexes is now quite significant, the maturity indicator similarities in Plates 16 and 17 again emphasize the fact that indicator series of bones in themselves are neither age-limited nor sex-limited.

Hindfoot

Outlines of surfaces in the ankle, lateral view: The progress of reciprocal shaping of margins of surfaces within the ankle should now be gauged in terms of the extent of the upper articular facet of the ankle. Accordingly, more than two-thirds of the outline of each of the following margins are reciprocally curved; metaphysis of tibia, inner bone margin of tibial epiphysis, and trochlea of talus.

Medial malleolus, lateral view: The outline of the medial malleolus projects below the articular facet. From the lateral view as well as an oblique view, its lower margin extends below the crest of the trochlea of the talus.

Midfoot

Cuboid, both views: Its calcaneal articular facet is etched and slightly concave centrally. A comparison of the dorsoplantar and lateral views of the facet will make it clear that the more distal outline is along its lateral margin.

Here, as in Plate 16, a short white line near the plantar surface marks the entrance of the groove for the tendon of the peroneus longus muscle.

Medial cuneiform, lateral view: The small notch in its lateral margin, described with Plate 16, is in the same transverse plane as the small etched marking on its medial side. The latter marking indicates the site of attachment of the tibialis anterior muscle. These markings are similar in Plates 16 and 17.

Navicular, both views: The margin of its talar articular facet has become thickened and is slightly concave. The lower (plantar) half of the bone, as in Plate 16, has a greater proximal-to-distal diameter than the dorsal half. A review of the naviculars in Plates 13 to 17 will clarify the fact that the bone acquires its characteristic contours rather rapidly under normal conditions of ossification.

Forefoot

Epiphysis of metatarsal V, dorsoplantar view: This girl's film series shows that the epiphysis of the fifth metatarsal in her foot developed from a single ossification center. Compound onset of ossification is frequently seen, and has been illustrated by the film series of the boy used for Plates 14, 15, 16, and 19. The outer bone margin of this epiphysis is now flattened distally. Its inner bone margin and metaphysis are reciprocally shaped.

Phalangeal articular facets, dorsoplantar view: The epiphyseal facets of the proximal phalanges are distinctly outlined. Each facet is now as wide as the adjacent epiphysis of the metatarsal. Thus reciprocal shaping is in process between pairs of articular surfaces throughout the foot, including the facets of the latest calcifying bone growth centers of the forefoot, namely, fifth metatarsal and fifth proximal phalanx.

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 6 years 6 months for boys and 5 years 0 months for girls.

SELECTED MATURITY INDICATORS

Hindfoot

Talus, lateral view: The posterior talocalcaneal articular facet is extensively flattened. Accordingly a rounded angle of demarcation is forming at the junction of the posterior surface of the trochlea and the articular facet. This osseous corner will designate the posterior extent of the lower ankle joint surface. For several standards the indentation on the neck of the talus at the junction of the trochlea and the free portion of the dorsal surface has clearly marked the excursion of the tibia forward upon the talus.

Hindfoot and Midfoot

Mid-tarsal joint, both views: The navicular has lost its appearance of a "bone island" in a large space of lesser density.

The mid-tarsal joint is derived from four bones. Reciprocal shaping of the talus and navicular and of the calcaneus and cuboid has been established centrally in each of the two parts of this articulation.

Calcaneocuboid joint, lateral view: An indentation has formed in the distal surface of the calcaneus. This indentation and the deepest portion of the sinus tarsi in the calcaneus are in the same horizontal plane. The articular facet of the cuboid is also distinctly etched opposite the indentation, thereby marking the anatomical center of the calcaneocuboid joint.

Midfoot and Forefoot

The navicular and the adjacent parts of the margins of the three cuneiform bones have begun to shape reciprocally.

Both the midfoot and the forefoot display uniform flattening of the articular facets.

Reciprocal shaping of metaphyses and inner bone margins has been uniformly established throughout short bones of the foot.

MALE, SKELETAL AGE, 6.5 YEARS
FEMALE, SKELETAL AGE, 5.0 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 6 years 9 months for boys and 5 years 2 months for girls.

SELECTED MATURITY INDICATORS

This Plate continues the film series of the boy whose radiographs were used for Plates 14, 15, and 16. Plate 18 was made from a girl's film. The bone ages assigned to Plates 18 and 19 are similar and the maturity indicators in the two plates should be quite similar.

Hindfoot

Talus, lateral view: In Plate 23 it will be apparent that the entire trochlea is concave centrally. Here the concavity is beginning to be visible from the neck of the talus backward over the crest of the trochlea.

Calcaneus, lateral view: With Plate 11 mention was made that a groove would form between its anterior surface and a small osseous "bump" which was forming on the plantar margin of the bone shadow. A beveled outline has appeared at the anterior-plantar corner with a slight indentation close behind it. The anterior tubercle has thus begun to be visible in the film.

The indention in the anterior surface, first visible in Plate 18, is distinct in this plate.

Ossification of the epiphysis is just beginning. In the original film, several small bone particles were visible directly opposite the most ruffled portion of the metaphysis, but they are indistinct in the halftone.

Midfoot

Cuboid, lateral view: The anterior portion of the groove for the tendon of the peroneus longus muscle is becoming visible within the bone shadow.

Navicular, both views: It is noteworthy that the articular facets of the two naviculars in Plates 18 and 19 are similar in shape although the curvatures of the anterior surfaces of the taluses differ significantly.

In dorsoplantar views, the distal surface of the navicular will begin to present an obtuse angle, thereby showing the extent of its two cuneiform articular facets.

Plantar margins of the cuneiform bones, dorsoplantar view: Any dense white outline within these bone shadows will be in sub-dorsal surfaces of the bones and chiefly in plantar surfaces. A plantar marking, for example, has formed medially within the intermediate cuneiform.

Forefoot

Metatarsals, dorsoplantar view: The "nick" in the outer bone margin of the epiphysis of this metatarsal V, described with Plate 17, has disappeared; evidence of compound onset of ossification of the epiphysis had thus disappeared. The outer bone margin of the epiphysis now shows a typical flattened articular facet and flattened sides.

The strip of lesser density within each metatarsal is quite uniform.

Phalanges, dorsoplantar view: Throughout the forefoot, the proximal articular margins are flat or convex. The adjacent distal facets are concave and have the greater transverse dimension. These differences in dimension are beginning to be visible in the four lateral toes where the difference is apparent before it is seen in the great toe.

MALE, SKELETAL AGE, 6.7 YEARS
FEMALE, SKELETAL AGE, 5.2 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 8 years 0 months for boys and 6 years 3 months for girls.

SELECTED MATURITY INDICATORS

Hindfoot

Differential markings within the talus, lateral view: The medial and lateral margins of the crest of the trochlea have become thickened. Accordingly, the concavity of the trochlea can be traced backward and downward from the neck of the talus for more than half its extent.

Calcaneus, lateral view: The epiphyseal bone growth center now contains several osseous particles. The largest ossicle is positioned on the longest axis of the epiphysis, and its shape indicates the direction of the axis.

The small indentation on the plantar surface near the anterior tubercle mentioned with the preceding plate is now distinct. It marks the entrance of the groove for the long plantar ligament.

Midfoot

Cuboid, both views: A triangular outline projects backward from the cuboid toward the calcaneus. This is the outline of the medial surface of the bone.

The squarish osseous corner at the junction of its posterior, lateral, and plantar surfaces is distinctly outlined.

Navicular, both views: Its distal margin and its concave talar margin are shaping to the curvature of the distal surface of the talus which remains convex. Thus parallelism of outlines has been established dorsally in the latest of the tarsals to begin its ossification.

Inter-tarsal joints, both views: The free dorsal surfaces of the navicular and three cuneiform bones have become flattened. Blunted osseous corners are forming between the free surfaces and the inter-tarsal articular surfaces on the individual bones.

The facets which face the forefoot tend to be convex; those which face the hindfoot tend to be concave. The facets which face medially tend to be flat or beveled. These differences are becoming apparent throughout the midfoot.

Forefoot

Metatarsals, dorsoplantar view: Osseous beaks and sharp buttresses are forming at the junction of each metaphysis and its diaphysis. The metaphyses present thick white outlines along strips of lesser density. The terminal plates of the epiphyses and the etched outlines of the metaphyses are parallel throughout their extent.

Phalanges, dorsoplantar view: The epiphysis of the distal phalanx of the great toe is beginning to curve distally, that is, to cap the shaft on its medial side.

MALE, SKELETAL AGE, 8.0 YEARS
FEMALE, SKELETAL AGE, 6.2 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 8 years 9 months for boys and 6 years 10 months for girls.

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: It is now apparent that the transverse dimension of the epiphyseal growth cartilage plate, as gauged by the extent of the articular facet or sub-articular surface, is less than the dimension of the diaphyseal plate.

The growth cartilage plate of an epiphysis is beneath the articular facet, and that of the diaphysis is within the radiographic strip of lesser density in the shaft.

Talus, lateral view: The calcaneal margin of the silhouette is concave except for a short, beveled anterior portion of the margin. This beveled portion represents its anterior calcaneal facet.

Calcaneus, lateral view: The outer bone margin (posterior surface) of the epiphysis is smooth and convex. The strip of lesser density between the epiphysis and metaphysis is quite uniform although it remains relatively thick.

In the original film, several tiny osseous particles can be seen clearly between the epiphysis and metaphysis. This is one of the few epiphyses in the body in which the inner bone margin remains roughened after the strip of lesser density has begun to appear uniform centrally.

Midfoot and Forefoot

Tarsals, lateral view: Osseous corners have become increasingly squarish between the dorsal (free) and the medial and lateral (articular) surfaces.

Tarsals, dorsoplantar view: The adjacent articular facets of the navicular and the medial cuneiform are small and flat.

The distal margin of the medial cuneiform and the inner bone margin and metaphysis of metatarsal I are similarly beveled.

The adjacent articular facets of the three cuneiforms are reciprocally shaped.

A distinct white marking has formed along the lateral side of the medial cuneiform; this surface is concave distally. The marking projects toward the lateral osseous corner of the epiphysis of the first metatarsal.

In Plate 16, a small etched marking was visible on the medial side of the medial cuneiform, near its distal surface. A shallow indented outline now replaces that marking.

Metatarsals, dorsoplantar view: Within each metatarsal the transverse dimension of the metaphysis is now greater than the corresponding dimension of the articular facet in the epiphysis, a feature or characteristic seen earlier in the distal end of the tibia.

Metatarsal-phalangeal joint surfaces, dorsoplantar view: Excepting the great toe, the phalangeal articular facets are wider than the adjacent (metatarsal) articular facets.

MALE, SKELETAL AGE, 8.8 YEARS
FEMALE, SKELETAL AGE, 6.8 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 9 years 9 months for boys and 7 years 6 months for girls.

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: Hereafter the dimensions of the inner bone margin and metaphysis are equal.

The metaphysis projects downward over the anterior surface of the (distal) epiphysis of the tibia; this lipping is analogous to the capping of a metaphysis by the epiphysis. In standard Plates 19 to 22 of the knee atlas, it is evident that the tongue of the proximal tibial epiphysis develops concurrently with this metaphyseal lipping at the distal end.

In Plate 16, the medial malleolus began to project below the articular facet of the upper ankle-joint surface. Here the anterior margin of the malleolus is aligned with the anterior margin of the diaphysis. The posterior margin of the lateral malleolus, in the fibular epiphysis, is also aligned with the margin of its diaphysis.

Talus and calcaneus, lateral view: On the plantar surface of the talus, the posterior articular facet has begun to curve over the calcaneus.

The osseous "beak" of the calcaneus articulates with the side of the talus distally. The beak shows here its typical horizontal trabecular pattern. The trabecular band which formed under the sustentaculum tali now extends forward to the indentation on the anterior margin of the calcaneus.

Hindfoot, Midfoot and Forefoot

In the lateral view, the dorsal margins of the talus, navicular, medial cuneiform, and first metatarsal form an (interrupted) outline along the dorsum of the foot.

Tarsometatarsal articulation, dorsoplantar view: The tarsometatarsal joint includes the bases of the five metatarsals and the distal row of tarsals. The slope of the most medial joint is essentially transverse, and its facets are now quite flat. The most lateral of the five joints, between the base of the fifth metatarsal and the cuboid, has distinctly beveled facets. The fourth, third, second and first joints of the row are distal to the fifth joint. Accordingly, we may say that the tarsometatarsal joint is compound and beveled, sloping distally and medialy toward the great toe.

Forefoot

Sub-articular margins, dorsoplantar view: The shape of the articular facets has been established in the proximal phalanges as concave, and in the distal phalanx of the great toe as well. The dense white outline of each facet indicates extensive modeling of the sub-articular layers of bone. These evidences of modeling become distinct as soon as an epiphysis of a bone becomes slightly wider than its metaphysis.

The distal margin of the proximal phalanx of the great toe is beginning to appear indented.

MALE, SKELETAL AGE, 9.8 YEARS
FEMALE, SKELETAL AGE, 7.5 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 10 years 6 months for boys and 8 years 0 months for girls.

SKELETAL MATURITY INDICATORS

Hindfoot

Upper ankle joint surface, lateral view: The extent of the upper joint surface is clearly marked off anteriorly by a squarish osseous corner. The fibula (lateral wall) is obscured.

Lower ankle joint surface, lateral view: By Plate 19, it was evident that the trochlea of the talus is concave. Well-defined lateral and medial margins have developed over the crest. The denser white outline is that in the lateral margin, and is the earlier to develop. The medial (thinner) margin usually projects above the lateral margin, and its arc is larger.

Calcaneus, lateral view: The roughened appearance of the inner bone margin of the epiphysis has been reduced. The upper part of the metaphysis is slightly beveled; it may remain ruffled, or, it may be smooth. In many calcanei, a second epiphyseal ossification center now begins to appear opposite this upper portion of the metaphysis.

The outline of the sustentaculum tali can be traced within the bone shadow. Notice that it appears in the bone shadow on the same level as the concavity in the anterior margin of the calcaneus.

Midfoot

Cuboid, both views: Its calcaneal surface has become concave. From the dorsoplantar view, the position of the groove for the tendon of the peroneus longus muscle can be identified as adjacent to an area of lesser density immediately within the lateral side of the bone shadow.

Lateral and intermediate cuneiforms, dorsoplantar view: The medial markings on their plantar surfaces can be traced, within the medial portions of the shadows.

Medial cuneiform, dorsoplantar view: Its plantar surface (ridge) is represented by the area of greater density within the bone shadow. The medial margin (marking) of its plantar surface is seldom distinctly outlined in a film.

Navicular, dorsoplantar view: Its medial (free) side is beginning to appear beveled. The degree of beveling varies according to the prominence of the tubercle of the navicular. The curvature of its distal surface now conforms to the shape of the adjacent cuneiform outlines.

Forefoot

Metatarsals, dorsoplantar view: The dense trabecular portion within each epiphyseal shadow, resembling the plantar ridges of tarsals, aids in depicting the extent of each articular facet. The epiphyseal sides are distinctly flattened.

Phalanges, dorsoplantar view: The epiphyses of the (two) phalanges of the great toe have begun to cap their metaphyses medially.

The "sides" of the epiphyses of the proximal phalanges of the second, third, and fourth toes are no longer pointed; the extent of the articular facets can be easily identified hereafter.

MALE, SKELETAL AGE, 10.5 YEARS
FEMALE, SKELETAL AGE, 8.0 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 12 years 0 months for boys and 9 years 2 months for girls.

SELECTED MATURITY INDICATORS

Hindfoot

Upper portion of the ankle joint, lateral view: The inner bone margin and the articular facet of the tibial epiphysis each form a distinct angle of demarcation with the anterior "side" (surface) of the epiphysis. Posteriorly the epiphyseal outlines remain thin and indistinct.

Lower portion of the ankle joint, lateral view: The medial and lateral margins of the trochlea can be traced backward from the crest to the posterior tubercle.

Since Plate 4, dense trabecular patterns have filled each of the trochleas. The dense portion of the bone now extends to the center of the talus, and into the triangular lateral wall of the sinus tarsi. In the anterior portion of the talus, a horizontal trabecular pattern has become visible. No doubt this latter pattern is continuous from the dense subtrochlear portion of the bone.

A tiny bone nodule is visible close to the posterior tubercle of the talus; we have observed one ossification center here routinely. Sometimes, as in this child's film series, another ossicle forms at the posterior tubercle after a first ossicle has become fused with the talus. It is usually the second ossicle which remains separated in the adult foot. In either case, a separated (adult) nodule is called the os trigonum. The ossicle marks the position of the posterior end of the groove for the tendon of the flexor hallucis longus muscle.

Calcaneus, lateral view: The squarish outline of the sustentaculum tali is visible within the silhouette and across the groove of the calcaneus. The margin of the middle talocalcaneal facet appears as the middle etched outline.

The calcaneal portion of the posterior talocalcaneal joint is begining to appear concave.

Midfoot and Forefoot

The mid-tarsal joint, both views: The full span of each of the four articular facets can be identified by means of osseous corners. Trabecular patterns of differential density within the calcaneus, talus, navicular and cuboid now extend to the structural center of each articular facet.

Navicular, dorsoplantar view: Within the bone shadow, the concave articular arc of its talar surface "caps" the anterior surface of the talus. Bone now projects beyond the medial end of the arc; the tuberosity of the navicular is calcifying. Sometimes the tuberosity develops from a separate ossification center to become one of the most frequently-occurring accessory bones of the adult foot.

Forefoot

Metatarsals, dorsoplantar view: Each of the five growth cartilage plates within the metatarsals has been reduced to uniform thickness across the entire shaft.

Distal epiphysis of the great toe, dorsoplantar view: A tiny osseous nodule is visible at the medial end of the inner bone margin of the distal phalanx. This nodule later fused with the margin before epiphyseal-diaphyseal fusion began in the phalanx. Compare the "capping" outline, including the nodule, with the analogous outline (an inner bone margin without an accessory nodule) in Plate 25.

PLATE 24

MALE, SKELETAL AGE, 12.0 YEARS
FEMALE, SKELETAL AGE, 9.2 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in the plate is 13 years 0 months for boys and 10 years 0 months for girls.

SELECTED MATURITY INDICATORS

Hindfoot

Upper portion of ankle, lateral view: The tibial epiphysis has begun to "cap" the metaphysis posteriorly. The angle of demarcation between the posterior (free) side of the epiphysis and inner bone margin is a sharp angle. A similar, distinct angle is visible in the fibula.

Note the similarity in thickness of the growth cartilage plates in the (slender) fibular shaft and (thick) tibial shaft.

Ankle and heel, lateral view: A perpendicular plane, if placed upon the lowest bony point of the heel, would stand behind the center of the posterior talocalcaneal joint and the highest margin on the crest of the trochlea. Beginning with Plate 13, a comparison of successive plates shows the relationship of such a plane to key articular facets and trabecular patterns within the bone shadows. All joint centers of the hindfoot are anterior to this plane, as well as the thickest portions of the calcaneus and talus. The entire calcaneal epiphysis and its growth cartilage plate are behind this plane.

Midfoot

Pre-adult contours, both views: Comparison of the joint spaces in this plate with those of Plate 30 will show that their contours resemble those of the young adult foot. Most of the osseous corners, denoting the full dimensions of the articular surfaces, remain blunted and will become more prominent.

Forefoot

Pre-adult contours, both views: Flattening of the epiphyseal sides is in process throughout the forefoot. As soon as flattening of the sides of an epiphysis has occurred, that is, diaphyseal widening is nearly completed, the epiphysis begins to cap the metaphysis. Capping is now in process in some of the bones of the forefoot.

The slight haziness of the strips of lesser density indicates approaching epiphyseal-diaphyseal fusion.

Accessory Bones

Os trigonum, lateral view: With Plate 24, the significance of the location of the os trigonum with respect to the posterior tubercle of the talus was mentioned. The nodule is medial to the posterior tubercle. In a radiograph, the nodule is either temporarily or permanently separated from the talus by a strip of lesser density. This particular os trigonum later fused with the talus.

Os Vesalianum, dorsoplantar view: In the film, a thin bone chip is visible along the lateral side of the base of the fifth metatarsal, separated from the base by a strip of lesser density. The nodule is barely visible in the halftone. This particular os Vesalianum later united with the metatarsal.

Sesamoids of the great toe, dorsoplantar view: Within the shadow of the distal end of the metatarsal of the great toe, two oval bone nodules can be traced. Sometimes each sesamoid is compound.

The typical order of onset of ossification of the centers described above is: (1) os trigonum, (2) os Vesalianum, (3) lateral sesamoid, and (4) medial sesamoid. Inversion of the order of onset of ossification of the two sesamoids is not significant, for they frequently begin to calcify simultaneously.

MALE, SKELETAL AGE, 13.0 YEARS
FEMALE, SKELETAL AGE, 10.0 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 14 years 0 months for the male foot and 11 years 0 months for the female foot.

SELECTED MATURITY INDICATORS

Hindfoot

Tibia, lateral view: The entire strip of lesser density has become hazy. Epiphyseal-diaphyseal fusion is well advanced in the anterior portion of the bone; the dense white terminal plate remains intact.

Calcaneus, lateral view: The small upper ossification center is uniting with the major portion of the epiphysis. The growth cartilage plate is thin and uniform. The outline of the entire metaphysis can be traced.

Hindfoot and Midfoot Joints

It would be difficult to find significant differences between the contours of the joints here and those of a fully matured foot.

Navicular, both views: The tuberosity of the navicular is filled in with bone. It can be identified in the dorsoplantar view by means of its transverse trabecular pattern.

Forefoot

Epiphyseal-diaphyseal fusion, dorsoplantar view: The fusion process usually begins within the distal phalanx of the great toe. Slightly earlier, as a rule, the fusion process will be seen in the distal phalanges of the second, third and fourth toes, but these phalanges are not included routinely in skeletal age assessment.

Os Vesalianum, dorsoplantar view: In Plate 25, a small nodule was visible close to the lateral side of the base of the fifth metatarsal. There are no traces of a nodule here. While Plates 25 and 26 are feet of different children, the time span between first appearance and fusion of the nodule with the shaft proper is seldom more than a year.

MALE, SKELETAL AGE, 14.0 YEARS
FEMALE, SKELETAL AGE, 11.0 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 15 years 0 months for the male foot and 12 years 0 months for the female foot.

SELECTED MATURITY INDICATORS

Hindfoot

Upper portion of the ankle, lateral view: The strips of lesser density of both tibia and fibula are extensively bridged with bone. Fusion occurs earlier within the anterior portion of the shafts than within the posterior part. The terminal line in the tibia is thick and intact. The posterior end of the strip of lesser density in the fibula is still visible.

Ankle joint, lateral view: It is impossible to see significant differences between the developmental level of the joint here and in Plates 28 to 30.

Calcaneus, lateral view: Epiphyseal-diaphyseal fusion is well advanced beneath the portion of the epiphysis where the calcaneal tendon (of Achilles) is attached. A thinned portion of lesser density remains between the upper epiphyseal nodule and the metaphysis, and another between the metaphysis and epiphysis above the lowest bony point of the heel.

Midfoot

There is increased clarity of the bony outlines described in Plate 26.

Forefoot

Metatarsals, both views: Epiphyseal-diaphyseal fusion is well advanced in the second, third and fourth metatarsals; it is beginning centrally in the first and fifth metatarsals. All terminal lines remain visible in the original film.

Phalanges, dorsoplantar view: The growth cartilage plates have been eliminated from the phalanges of the second, third and fourth toes, and the fusion process has begun in the proximal phalanges of the first and fifth toes.

The fusion process appears completed in the distal phalanx of the great toe. The terminal line is thick across the shaft centrally and is very thin medially and laterally.

MALE, SKELETAL AGE, 15.0 YEARS
FEMALE, SKELETAL AGE, 12.0 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 16 years 0 months for boys and 13 years 3 months for girls.

SELECTED MATURITY INDICATORS

Epiphyseal-diaphyseal fusion is in process throughout the foot. It is radiographically complete in the distal phalanx of the great toe, although experience with anatomical specimens would show that an epiphysis with this radiographic appearance may not be attached inseparably to the diaphysis.

Our series shows that epiphyseal-diaphyseal fusion in foot bones seems to be completed dorsally before it is completed on the plantar surface.

The external layers of the tibial cortex appear smooth and uninterrupted, although remnants of terminal lines are visible. These lines may remain quite distinct throughout life.

The talus now has the typical "puppy's head" silhouette. The triangular "ear" or lateral process of the talus begins to take shape in Plate 11. It assumed its triangular appearance in Plate 21, having elongated gradually and since completed its growth.

By Plate 18 it was apparent that all distal joint surfaces were beginning to appear either flat or convex, and all proximal joint surfaces tend to be concave. In Plates 4 to 18, the typical shape of the center of each articular facet can be traced before the dimension of the facet is indicated in the film.

The lateral sesamoid of the great toe in this foot is compound.

MALE, SKELETAL AGE, 16.0 YEARS
FEMALE, SKELETAL AGE, 13.2 YEARS

INDIVIDUAL BONE AGES

The skeletal age assigned to each bone in this plate is 17 years 6 months for boys and 15 years 0 months for girls.

Mean Ages for Epiphyseal-diaphyseal Fusion: As was stated in our chapter on Design of the Standard of Reference, the plates have been selected to designate a moderate rate of skeletal development in the foot and ankle. This plate was selected after a modal film for each sex had been drawn at each examination age; one hundred films of boys and one hundred films of girls were used at each examination age. In the following tabulation, we have summarized the assessed epiphyseal-diaphyseal fusion age for two hundred of the adolescent children whose films were used in the preparation of this standard of reference.

Bones arrayed according to average fusion age (male):	*Male:* *Mean:* (*Years*)	*Male:* *S.D.*	*Female:* *Mean:* (*Years*)	*Female:* *S.D.*
Distal phalanx, toe 4	14.6	1.2	11.5	1.3
Distal phalanx, toe 2	14.7	1.2	11.8	1.3
Distal phalanx, toe 3	14.7	1.2	11.7	1.2
Distal phalanx, toe 1	15.3	1.1	13.0	1.2
Proximal phalanx, toe 2	15.6	1.1	13.4	1.1
Proximal phalanx, toe 3	15.6	1.0	13.3	1.0
Proximal phalanx, toe 4	15.6	1.1	13.4	1.0
Metatarsal I	15.8	1.1	13.7	1.1
Metatarsal II	15.8	1.0	13.9	1.0
Metatarsal III	15.8	1.1	13.9	1.0
Calcaneus	15.8	1.0	13.8	1.1
Proximal phalanx, toe 1	15.9	1.1	13.6	1.0
Metatarsal IV	15.9	1.0	14.0	1.0
Metatarsal V	16.0	1.1	14.1	1.0
Proximal phalanx, toe 5	16.0	1.1	13.7	1.1
Distal end of tibia	16.4	1.1	14.4	1.1
Distal end of fibula	16.4	1.1	14.1	1.1

SELECTED MATURITY INDICATORS

Epiphyseal-diaphyseal fusion is radiographically complete throughout the forefoot except for a tiny portion of the cortex of the fifth metatarsal.

An accessory bone, os naviculare, completes the deep arc of the distal talonavicular joint surface. Two later films of this girl's foot, taken at annual intervals, show no further fusion of this nodule and the navicular.

MALE, SKELETAL AGE, 17.5 YEARS
FEMALE, SKELETAL AGE, 15.0 YEARS

This is the modal film of the 100 eighteen year old boys.

Epiphyseal-diaphyseal fusion is radiographically complete throughout the region, and the tarsals have shown no significant changes in maturity indicators since Plate 28.

The assessor will readily understand why we usually designate the bones of a young adult's foot which match this standard plate as "at full young maturity level" instead of assigning each bone an age equivalent.

MALE, SKELETAL AGE, 18.0 YEARS
FEMALE, SKELETAL AGE, 15.2 YEARS

PLATE 31

Foot of a healthy young woman age 28 years; mother of four of our Research Series children. Her hand films have been reproduced on pages 181 and 183 of the Greulich and Pyle atlas, second edition (2).

PLATE 31

PART III

SKELETAL MATURITY INDICATORS

S. Idell Pyle, Normand L. Hoerr
Carl C Francis
William H. Golden, Artist

Skeletal Maturity Indicators of Individual Bones and Joints

OUR PURPOSE in this section of the atlas is to describe and illustrate several series of changes in shape of the regularly occurring bones of the foot and ankle during their postnatal development. Each series consists of tracings of a whole bone or an epiphyseal end of the bone as seen in radiographs. These transitional processes and markings aid in identifying the developmental level of a bone.

We primarily selected the sets of markings and processes from those listed for fully developed bones of the region by the International Nomenclature Committee of Anatomists in 1955. Insofar as it has been logical, the series for the foot and ankle were chosen to resemble those for bones of the hand and wrist[2] so that the two skeletal regions might be readily compared.

Obviously, in the radiographic silhouette of a region, the markings and processes usually depict superimposed portions of a bone's cortex. Some especial terminology such as "osseous corner" and "articular facet" have been introduced which apply to such plane views of a bone.

Each drawing shows schematically the most typical radiographic margin of a regularly occurring bone at a particular stage of its development as we observed it in our film series. Opposite each sketch are listed the ordinal numbers of two standard plates in Part II. In the first or younger plate of each pair, the maturity indicator referred to has not yet appeared, it is present in the second or older standard halftone. For example, the earliest maturity indicator of the distal epiphysis of the tibia in its initial osseous nodule. The epiphysis in Plate 4 contains a single small nodule; Plate 3 shows no evidence of onset of ossification in the epiphysis. Also in Plate 4, the shape of the nodule indicates that its ossification began shortly after Plate 3.

We have followed the procedure of printing in boldface the number of the standard Plate nearest in time to the beginning of visibility of the sketched feature to indicate its temporal relationship to the two Plates. When neither of the two plate numbers is entered in boldface opposite the sketch, we have estimated that the indicator has appeared approximately midway between the two standard halftones.

This method of depicting the temporal relationships of indicators is the same as that followed in the Hand Atlas,[3] although in that atlas separate standards are provided for the male and the female. Girls and boys, on the same developmental schedule, differ in time of expected appearance of a maturity indicator. The anatomical precocity of girls is demonstrated by the individual bone ages and the skeletal age (foot) as well. Thus continuing with the tibial epiphysis as an example, two pairs of bone ages have been assigned to the tibia in Plates 3 and 4 as of the male foot and the female foot, respectively.

The sketches of the maturity indicator series are most helpful if they are used to augment the selected maturity indicators described in conjunction with the standard Plates. Presumably they are regularly occurring features of the bones in the feet of all children. The tangibility of contour markings provides a degree of definiteness that is especially reassuring when one is summarizing a child's skeletal developmental status—a procedure in which there is a tendency to rely disproportionately upon size of the nodule particularly in the early stages of development of a bone.

Maturity Indicators of the Distal Ends of the Tibia and Fibula

These maturity indicator series, showing two views of the ankle joint, were traced from the film series of one Boston child; both views were made at the same examination. The lateral series was traced from foot films, the anteroposterior series from tibial-fibular films. The plate numbers with each description pertain *only* to the lateral view.

Views:

Lateral | Anteroposterior

I

The distal ends of the shafts are slightly flared, and the metaphyses are smooth and flat. The epiphyses are as yet entirely cartilaginous.

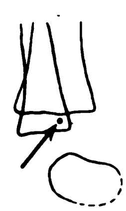
	Tibia	Fibula
Standard Plates	*1* and 2	*1* and 2

II

Tibia. The initial ossification center in the epiphysis forms slightly nearer the anterior than the posterior margin of the shaft. The metaphysis is slightly more flared posteriorly.

Fibula. The epiphysis remains entirely cartilaginous.

	Tibia	Fibula
Standard Plates	*3* and 4	3 and *4*

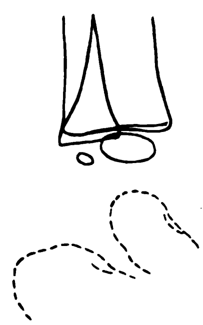


III

Tibia. The inner bone margin has become flattened centrally; there the growth cartilage plate has been reduced to its characteristic thickness. As a rule, the epiphysis is pointed posteriorly and is relatively rounded and thick anteriorly.

Fibula. The initial ossification center forms slightly nearer the posterior than the anterior surface of the shaft.

	Tibia	Fibula
Standard Plates	*6* and 7	*6* and 7



Maturity Indicators of the Distal Ends of the Tibia and Fibula

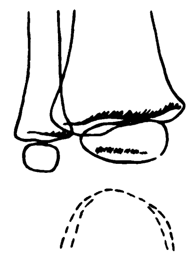
Views: Lateral Anteroposterior

IV

Tibia. A concavity has begun to be visible in the center of the outer bone margin; the outline of the articular facet is becoming visible.

Fibula. The inner bone margin has become flattened. At present the longest diameter of the epiphysis is transverse.

	Tibia	Fibula
Standard Plates	*8* and 9	8 and 9

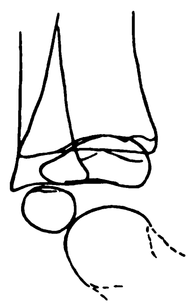


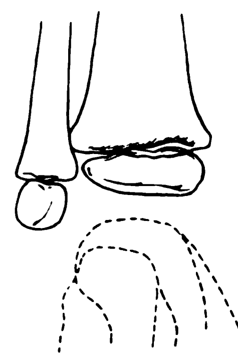
V

Tibia. The epiphysis is beveled and pointed posteriorly. Its diameter is equal to that of the shaft above the metaphysis.

Fibula. The sides of the epiphysis have become flattened. The terminal plate is beginning to be visible as a thin white outline along the inner bone margin. The growth cartilage plate has been reduced to its characteristic thickness centrally.

	Tibia	Fibula
Standard Plates	10 and *11*	10 and *11*



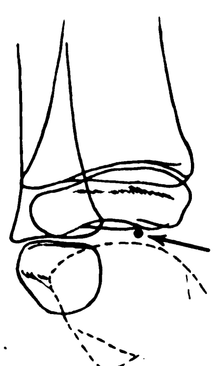


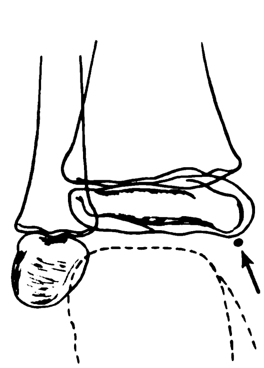
VI

Tibia. The anterior "side" of the epiphysis has become flattened and presently will begin to curve downward toward the trochlea. The arrow in the sketch points to the nodule which is the ossification center of the medial malleolus; the center is usually obscured in a direct lateral view of the foot by overlapping osseous margins.

Fibula. A transverse marking is forming within the shadow of the epiphysis. This white marking denotes the upper margin of the lateral malleolar fossa.

	Tibia	Fibula
Standard Plates	13 and *14*	13 and *14*





Maturity Indicators of the Distal Ends of the Tibia and Fibula

Views:

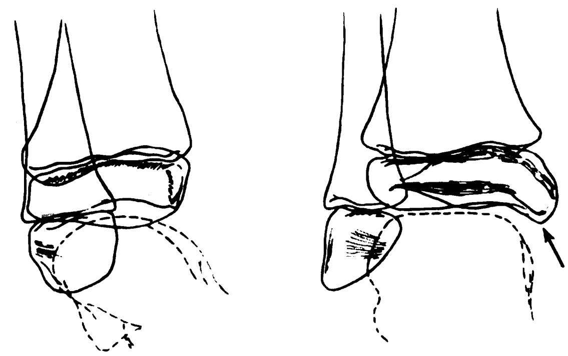
Lateral Anteroposterior

VII

Tibia. The anterior side of the epiphysis is beveled to conform to the width of the metaphysis; the articular facet will not become as wide as the metaphysis. The anterior side slopes toward the trochlea of the talus.

Fibula. The side of the epiphysis and the side of the diaphysis are aligned posteriorly. From an oblique view of the foot, it is clear that the epiphysis and metaphysis are aligned both anteriorly and posteriorly.

	Tibia	Fibula
Standard Plates	20 and *21*	*21* and 22

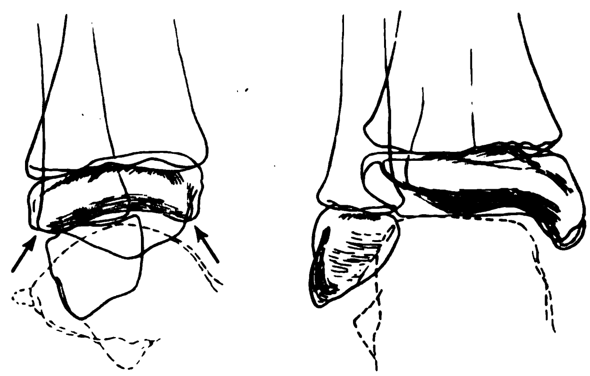


VIII

Tibia. The full extent of the articular facet is marked off by blunted osseous corners. The anterior corner forms slightly earlier than the posterior corner.
The medial malleolus projects below the crest of the trochlea.

Fibula. As a rule, only the posterior end of the strip of lesser density can be seen in the direct lateral view. There the terminal plate extends to the edge of the inner bone margin, indicating that the growth cartilage plate has become uniform.

	Tibia	Fibula
Standard Plates	23 and *24*	*24* and 25

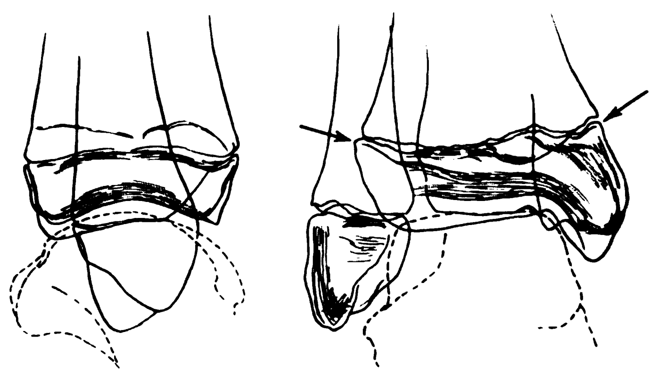


IX

Tibia. Reciprocal shaping of the inner bone margin and the metaphysis has been completed.
Anteriorly, within the bone shadow, the fuzzy appearance of the strip of lesser density is due to overlapping of the metaphysis upon the epiphysis. Epiphyseal-diaphyseal fusion has not begun.

Fibula. The etched terminal plate forms a sharp osseous corner with the posterior side of the epiphysis.

	Tibia	Fibula
Standard Plates	*25* and 26	*25* and 26



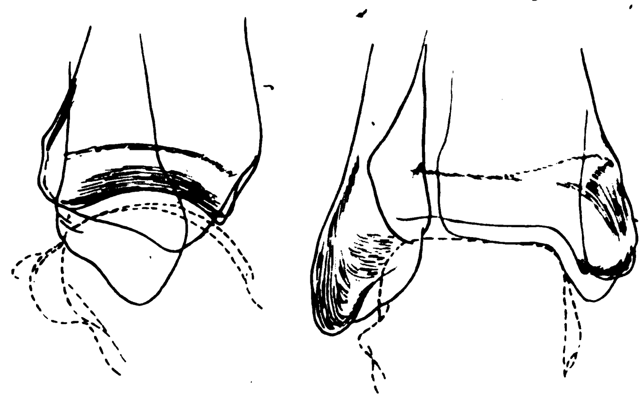
Maturity Indicators of the Distal Ends of the Tibia and Fibula

X

Both bones. Epiphyseal-diaphyseal fusion has been completed. Remnants of the terminal line may remain visible in each bone throughout life.

	Tibia	Fibula
Standard Plates	28 and 29	28 and 29

Views:



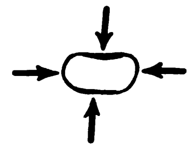
Maturity Indicators of the Talus

I

The nodule is oval with its longest dimension horizontal. Each arrow in the sketch points to the center of one of the four sub-divisions of the radiographic silhouette; dorsal, plantar (calcaneal), anterior (navicular), and posterior (trochlear) parts.
Localized shaping of the margins begins with a small indentation centrally in the dorsal margin.

Standard Plates 1 and 2

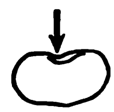
View:
Lateral



II

The indentation in the upper surface is etched; its modeling is beginning. Flattening and thickening of the plantar (calcaneal) margin is beginning directly below the upper indentation. These vertically-aligned markings designate the location of the neck of the talus.

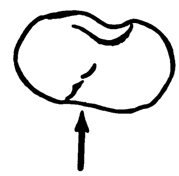
Standard Plates 1 and *2*



III

Within the bone shadow, a short outline of increased density begins to curve upward behind the talar groove on the plantar (calcaneal) surface. Ossification of the margin of the lateral process of the talus has begun.

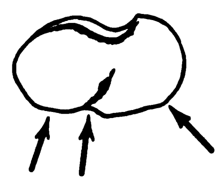
Standard Plates 4 and 5



IV

The middle arrow in the sketch points to the groove which divides the upper surface of the talocalcaneal joint into anterior and posterior facets. The left-hand arrow points to the initial flattening of the posterior facet. The right-hand arrow points to the junction of the anterior facet and the anterior (navicular) surface of the talus. This angle of demarcation is an important landmark in the structural center of the mid-tarsal joint.

Standard Plates *12* and 13



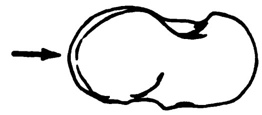
Maturity Indicators of the Talus

V

View:
Lateral

The trochlea (lower ankle joint surface) will be concave centrally when it is fully developed. The arrow points to the long axis of the bone. Above the arrow, the medial and lateral sides of the concavity begin to be visible on the crest of the trochlea.

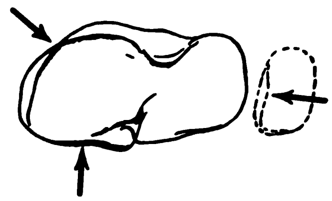
Standard Plates *12* and 13



VI

The roundness of the trochlea begins to appear reduced immediately behind the crest. The upper arrow points to the initial site of the flattening. The medial and lateral edges of the concavity can be traced backward from the crest.
The lower arrow points to the flattening of the posterior facet. The anterior facet is beginning to flatten.

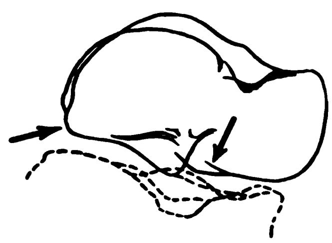
Standard Plates *13* and 14



VII

The left-hand arrow points to the intersection of the trochlea and the posterior talocalcaneal articular facet of the talus. There a short beveled outline is beginning to mark the site of the posterior tubercle of the talus. The arrow inside the sketch points to the site of the middle calcaneal facet of the talus.
The triangular lateral wall of the sinus tarsi is posterior to the arrow inside the sketch.

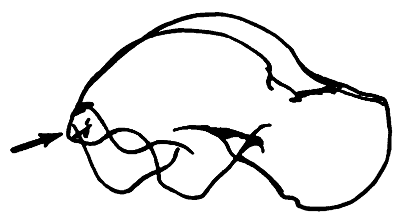
Standard Plates 22 and 23



VIII

The posterior talocalcaneal articular facet begins to cap the calcaneus. The arrow points to a small epiphysis-like nodule, the os trigonum, which develops adjacent to the posterior tubercle. The nodule and tubercle distinctly mark the entrance of the groove for the tendon of the flexor hallucis longus muscle. The tubercle is lateral to the groove.

Standard Plates 23 and *24*



View:
Lateral

IX

Young adult contours. The portion of the upper surface distal to the neck of the talus remains slightly roughened in contrast to the smooth trochlea.

Standard Plates *28* and 29

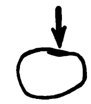
Maturity Indicators of the Calcaneus

I

The nodule is pyriform with its longest dimension horizontal and its largest part posterior. The circumference of the silhouette has four sub-divisions; upper (dorsal), anterior (cuboid), lower (plantar), and posterior (metaphyseal) margins.
Further localized shaping of the silhouette begins with a shallow indentation in the upper margin near the center. This is the forerunner marking of the calcaneal groove.

Standard Plates *1* and 2

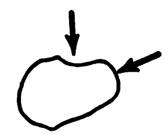
View:
Lateral



II

The plantar margin is beginning to appear flattened directly below the indentation in the upper margin. Behind the flattening, the lowest bony point of the heel is forming.
The indentation on the upper margin has become wide and shallow. The long axis of the nodule extends to the future center of the calcaneo-cuboid joint.

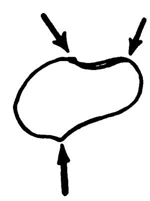
Standard Plates *1* and 2



III

The two upper arrows demarcate the portion of the the upper margin which is becoming etched and thickened, that is, modeled.
The lower arrow points to the lowest bony point of the heel which is now distinct.

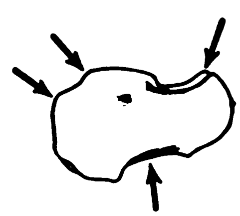
Standard Plates 4 and 5



IV

The posterior talocalcaneal articular facet is flattened centrally. The free or retro-articular portion of the upper surface, now modeled centrally, slopes off the posterior articular facet to the metaphysis.
The medial margin of the calcaneal groove begins to cast a taller shadow than does the lateral margin. The thickened outlines extend toward the osseous beak at the junction of the upper and anterior surfaces.
The plantar surface is thickened (modeled) distal to the lowest bony point of the heel.

Standard Plates 8 and 9

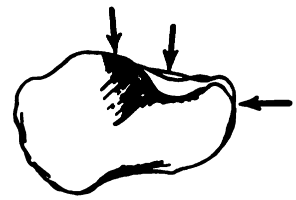


View:
Lateral

V

The middle arrow points to a flattened outline adjacent to the calcaneal groove; this is the facet of the sustentaculum tali.
The roundness of the anterior margin has been reduced; reciprocal shaping of the calcaneus and cuboid is in process centrally.
The (longitudinal) flattening of the posterior talocalcaneal articular facet has been increased.

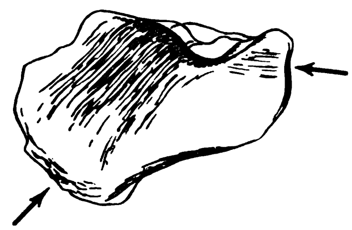
Standard Plates 13 and 14



VI

The anterior (cuboid) surface is beginning to appear indented. This indentation marks the structural center of the calcaneocuboid joint and the lower portion of the midtarsal joint as well. It is in the same horizontal plane as the sustentaculum tali.
The metaphysis is easily identified as the single roughened portion of the circumference of the silhouette. The degree of ruffling of its margin varies.

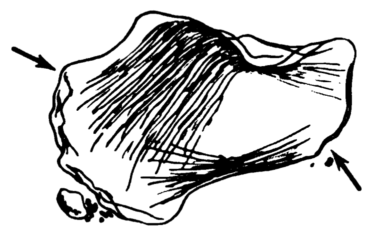
Standard Plates 17 and 18



VII

Ossification of the epiphysis begins, as a rule, with the appearance of a number of small osseous particles nearer the plantar end than the upper end of the metaphysis. The initial ossification center marks the site of insertion of the major portion of the calcaneal (Achilles) tendon.
A small indentation has begun to form distally on the plantar surface near the junction of the anterior and plantar margins of the silhouette. This indentation marks the groove for the long plantar ligament.

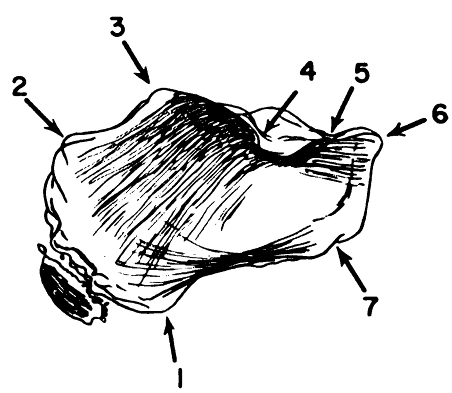
Standard Plates 20 and 21



VIII

The free and articular portions of the silhouette are marked off by a series of osseous corners. Starting with the initial osseous corner or lowest bony point of the heel and proceeding clock-wise, the corners mark off the circumference into the following segments. 1-2 is the metaphysis; 2-3 is the retro-articular portion of the upper surface; 3-4 is the posterior talocalcaneal articular facet; 4-5 is the calcaneal groove and the lower margin of the sinus tarsi; 5-6 is the anterior talocalcaneal facet; 6-7 is the (posterior) calcaneocuboid articular surface; and 7-1 is the plantar margin.

Standard Plates 21 and 22



Maturity Indicators of the Calcaneus

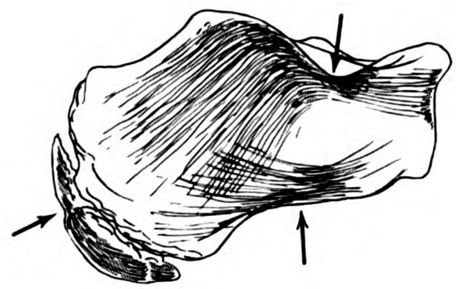
IX

The upper portion of the epiphysis, whenever it stems from a separate bone growth center, begins to unite with the major epiphyseal nodule. The epiphysis and metaphysis are shaping reciprocally, and the characteristic thickness of the growth cartilage plate can be identified centrally. The entire posterior surface of the epiphysis has become smooth.

It is now clear that the plane in which the modeling of the dorsal and plantar surfaces begins (upper and lower arrows) is the plane which marks (a) the anterior extent of the trochlea, that is, lower ankle joint surface, and (b) the position of the sustentaculum tali.

Standard Plates 23 and 24

View:
Lateral

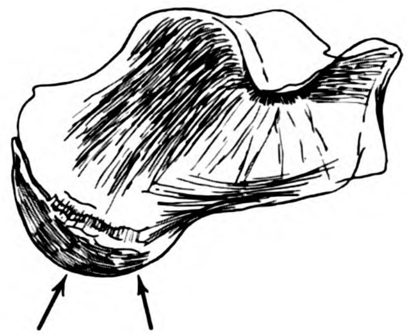


X

The epiphysis caps (covers) the lowest bony point of the heel completely; thus the lateral calcaneal tuberosity is in the epiphysis.

The strip of lesser density is very hazy. The outline of the metaphysis, however, can be traced.

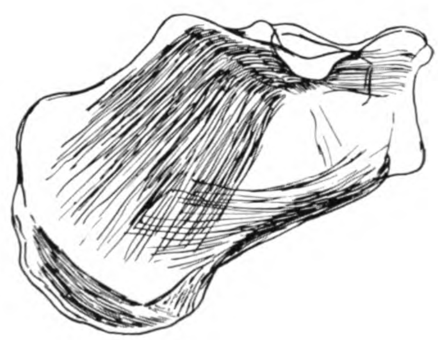
Standard Plates 25 and 26



XI

Adult contours have been established over the entire bone. Epiphyseal-diaphyseal fusion has been completed.

Standard Plates *28* and 29



Maturity Indicators of the Cuboid

Views:

Lateral | Dorsoplantar

I

Ossification begins with a small rounded cluster of nodules. If a line were drawn between the base of the fourth metatarsal and the greatest convexity of the anterior surface of the calcaneus, the line would pass through the cluster.

Standard Plates *1* and 2

II

Lateral view. The posterior (calcaneal) margin is flattened.

Dorsoplantar view. The medial (cuneiform) margin is flattened. The margins are smooth and the nodule is homogeneous.

Standard Plates 1 and *2*

III

Lateral view. The circumference of the nodule shows four sub-divisions; a slightly thickened posterior (calcaneal) margin, flattened dorsal and plantar margins, and a rounded distal margin.

Dorsoplantar view. Its lateral margin is slightly flattened, and its medial (cuneiform) margin is beveled.

Standard Plates *5* and 6

IV

Lateral view. The posterior (calcaneal) margin has become the tallest portion of the bone.

Dorsoplantar view. The arrow on the right points toward the navicular facet; as yet it resembles an enlarged osseous corner.

The upper arrow points to the median plane of the bone when a line is projected backward from the center of the base of the fourth metatarsal.

Standard Plates *9* and 10

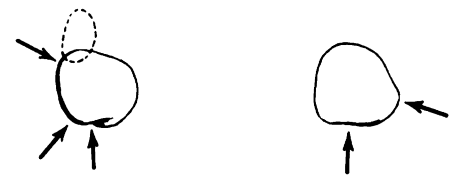
Maturity Indicators of the Cuboid

V

Lateral view. The vertical extent of the posterior (calcaneal) facet can be identified by two blunted osseous corners; they form between the facet and the dorsal surface and the plantar surface, respectively.
A small etched marking is developing on the plantar surface. Curving forward from this marking, a thin white outline within the shadow designates the edge of the groove of the tendon of the peroneus longus muscle.
Dorsoplantar view. The posterior (calcaneal) one-third of the bone is its widest portion. Both the navicular and the cuneiform facets have elongated.

Standard Plates *13* and 14

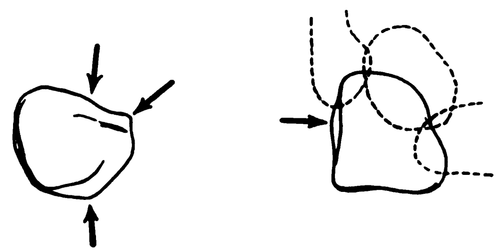
Views:
Lateral Dorsoplantar



VI

Lateral view. A triangular outline begins to project backward across the center of the posterior (calcaneal) margin. This is the posterior outline of the medial surface.
The three arrows designate the current extent of the three articular facets. Proceeding clock-wise from the upper arrow they are; the navicular, cuneiform, and anterior facets of the cuboid.
Dorsoplantar view. The arrow points to the posterior extent of the cuboid-fifth metatarsal joint, which is the most lateral of the tarsometatarsal joints.

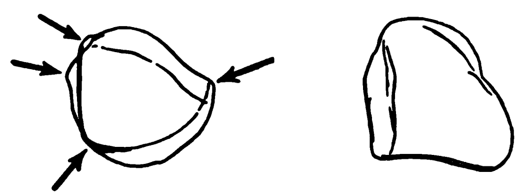
Standard Plates 18 and 19



VII

Lateral view. Blunted osseous corners demarcate the several sub-divisions of the circumference. The upper (left-hand) pair of arrows designates the extent of the facet on the cuboid which is central in the mid-tarsal articulation, its talonavicular facet. The lower and right-hand arrows designate the extent of the groove for the tendon of the peroneus longus muscle.
Dorsoplantar view. The entire posterior (calcaneal) facet is concave.

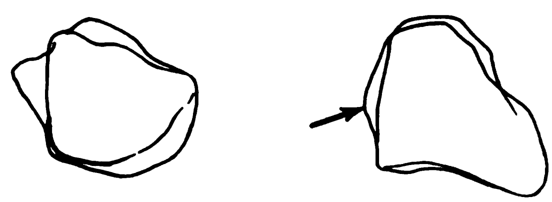
Standard Plates 21 and 22



VIII

Young adult contours. The outlines within the silhouettes aid in gauging the slope plantarward of the several surfaces of the bone.
The arrow points to the posterior corner of the lateral articular facet. Inside this margin a thinned area represents the location of the groove for the tendon of the peroneus longus mucle, so readily identified from the lateral view.

Standard Plates *28* and 29



Maturity Indicators of the Lateral Cuneiform and the Medial Cuneiform

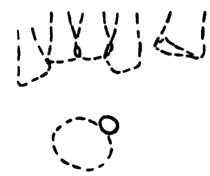
View:
Dorsoplantar

I

Lateral Cuneiform. Ossification begins, as a rule, with a single nodule. The center of ossification is close to the distal surface of the cuboid and is aligned with the medial side of the third metatarsal.

Medial Cuneiform. The bone is as yet entirely cartilaginous.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	*2* and 3	2 and 3

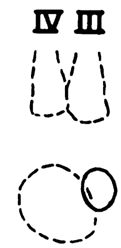


II

Lateral Cuneiform. The nodule has become oval and its cuboid and medial margins have become slightly flattened.

Medial Cuneiform. Entirely cartilaginous.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	*4* and 5	4 and 5

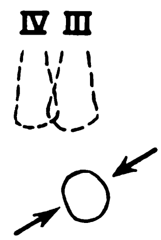


III

Lateral Cuneiform. The nodule has become elongated and its circumference shows four sub-divisions; the flattened cuboid and medial margins and the rounded distal and posterior margins.

Medial Cuneiform. The bone continues to be entirely cartilaginous.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	6 and 7	6 and 7

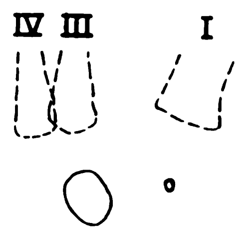


IV

Lateral Cuneiform. Flattening of its distal margin has begun. Its cuboid margin is becoming beveled and aligned according to the slope of the adjacent surface of the cuboid.

Medial Cuneiform. Ossification has begun; the bone growth center contains either a single nodule or multiple particles. The initial site of ossification is aligned with the long axis of the shaft of the first metatarsal.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	9 and 10	9 and *10*



Maturity Indicators of the Lateral Cuneiform and the Medial Cuneiform

V

Lateral Cuneiform. A thin marking begins to be visible within the bone shadow close to its medial surface. This marking is on the plantar ridge of the bone.

Medial Cuneiform. The osseous particles have coalesced. The nodule is centered with the epiphyseal nodule of the first metatarsal; their long axes form, approximately, a right angle.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	*13* and 14	12 and *13*

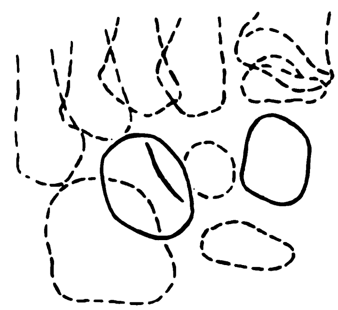
View:
Dorsoplantar

VI

Lateral Cuneiform. Within the bone shadow, the medial outline of the plantar ridge has become concave. The space between the cuneiform and base of the fourth metatarsal is very narrow.

Medial Cuneiform. The circumference of the nodule shows four sub-divisions; a well-flattened lateral margin, somewhat flattened medial, distal, and posterior margins.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	13 and *14*	13 and *14*

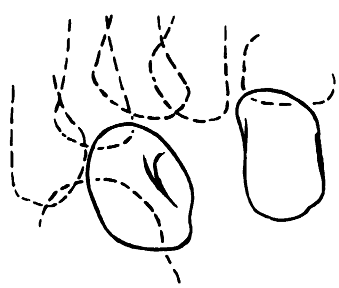


VII

Lateral Cuneiform. The (small) portion of the circumference adjacent to the navicular has begun to flatten. The posterior surface is distinctly flattened.

Medial Cuneiform. Both the distal and the navicular facets have begun to flatten. A blunted osseous corner has begun to project toward the base of the second metatarsal.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	16 and *17*	16 and *17*



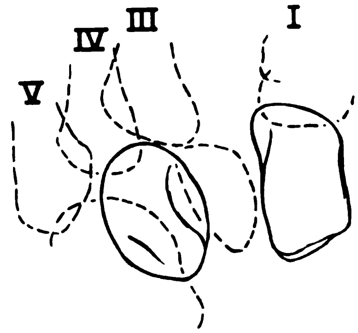
VIII

Lateral Cuneiform. The (lateral cuneiform) facet of the inter-cuneiform joint is concave. Inside the lateral portion of the bone shadow, a thin plantar marking is beginning to extend forward from the corner of the navicular facet. This marking soon becomes obscured by overlapping bone shadows.

Medial Cuneiform. A dense white outline is forming within the bone shadow close to its lateral margin; it is becoming concave distally. On the medial (free) side of the bone, a short etched marking begins to be visible directly opposite the indentation on the lateral side. This (earlier) modeling of the bone distally and the (subsequent) appearance of the etched marking medially designate the plane across the bone where the tendon of the tibialis anterior muscle is medially attached.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	18 and 19	18 and 19

View:
Dorsoplantar

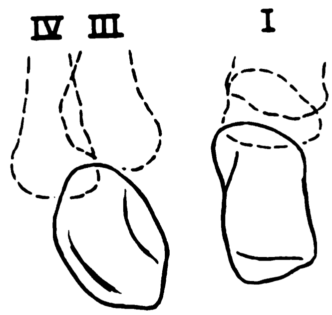


IX

Lateral Cuneiform. Blunted osesous corners are forming at the junctions of its navicular, cuboid, and metatarsal facets. The joint spaces are narrow and the shadows obscure these thinly outlined corners; however, they can be identified in the original film.

Medial Cuneiform. The margin of its navicular facet can be traced within the bone shadow. The facet is quite flat.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	19 and *20*	19 and *20*



Maturity Indicators of the Lateral Cuneiform and the Medial Cuneiform

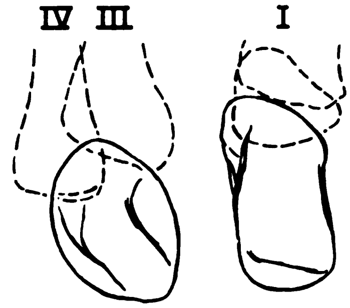
X

Lateral Cuneiform. Centrally, the medial and lateral plantar markings are now reciprocally curved.
The longest axis of the bone points distally to the interbase joint of the fourth and fifth metatarsals and proximally toward the navicular.

Medial Cuneiform. The adjacent surfaces of this cuneiform and the epiphysis of the metatarsal in the great toe are similarly beveled. Blunted osseous corners begin to demarcate the extent of each of its articular facets. The bone silhouette appears relatively narrow at the level of the medial marking which designates the site of attachment of the tendon of the tibialis anterior muscle.

	Lateral Cuneiform	Medial Cuneiform
Standard Plates	20 and *21*	20 and *21*

View:
Dorsoplantar

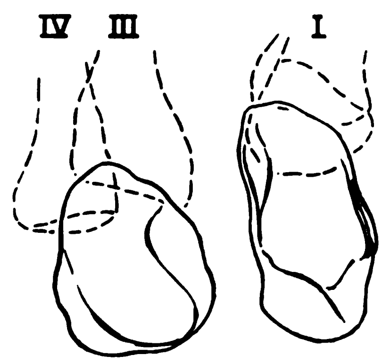


XI

Lateral Cuneiform. The medial and lateral sides of the bone are concave, insofar as their margins can be traced within the dense overlapping shadows of the tarsals.

Medial Cuneiform. The site of insertion of the tendon of the tibialis anterior muscle is characteristically quite flat in the adult bone. It is now distinctly thickened on the silhouette. The tendon is inserted immediately proximal to the initial small marking described at stage VIII.

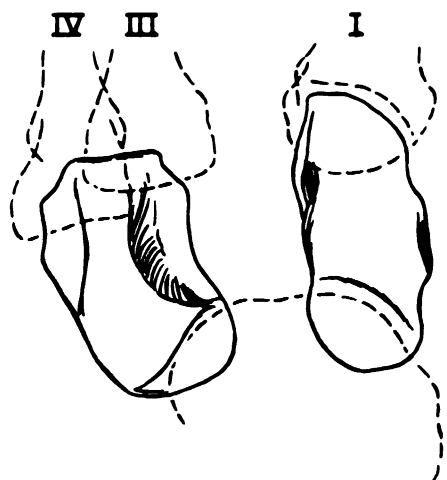
	Lateral Cuneiform	Medial Cuneiform
Standard Plates	23 and 24	23 and 24



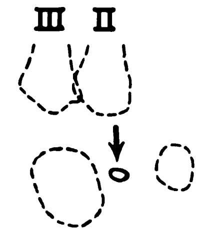
XII

Both bones. Young adult contours. The markings and marginal outlines within the silhouettes aid in gauging the slope of the articular facets.

Standard Plates	*28* and 29



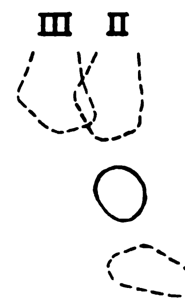
View:
Dorsoplantar



I

Ossification begins with a single nodule, or, occasionally, with multiple nodules. The center of ossification is aligned with the medial side of the second metatarsal.

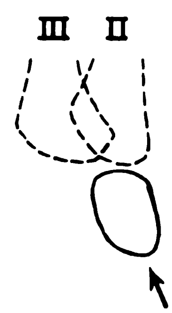
Standard Plates 11 and 12



II

The nodule is oval. Its longest axis points toward the navicular. Localized shaping of the silhouette begins with flattening of its lateral side. The remainder of the circumference is rounded.

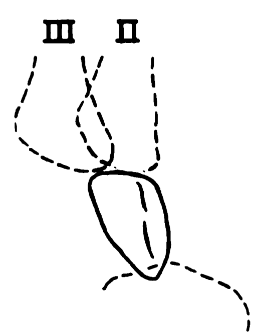
Standard Plates 14 and 15



III

The posterior half of the bone has become its narrowest portion. Its medial, lateral, and distal margins are distinctly flattened.

Standard Plates 15 and 16



IV

Thin white markings are becoming visible within the bone shadow. These markings are on the plantar ridge of the bone. Usually the medial marking becomes visible slightly in advance of the lateral marking.

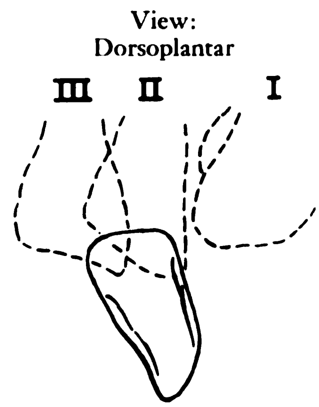
Standard Plates 18 and 19

Maturity Indicators of the Intermediate Cuneiform

V

The external outline of the sketch depicts the shape and extent of the dorsal surface of the bone. The medial and lateral markings within the silhouette depict the extent of the plantar ridge.
The slope of its medial side conforms with the slope of the lateral side of the epiphysis of the first metatarsal and of the adjacent surface of the medial cuneiform.
The lateral side of the bone is concave.

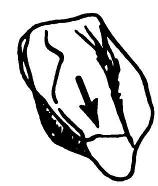
Standard Plates 20 and 21



VI

Blunted osseous corners demarcate the full extent of each articular facet. Its medial and lateral surfaces tend to be concave, particularly the lateral surface. Its metatarsal surface is quite flat. Its navicular articular facet displays a somewhat pointed dorsal outline which projects over the navicular; the actual articular facet is well flattened.

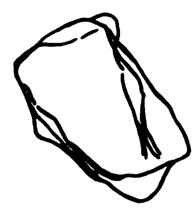
Standard Plates 21 and 22



VII

Young adult contours. The markings along the plantar ridge, although irregular, aid in gauging the slope of the articular portions of the bone.

Standard Plates 24 and 25



Maturity Indicators of the Navicular

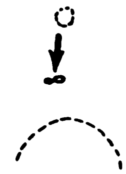
Views:

Lateral | Dorsoplantar

I

Ossification begins with either an oval cluster of particles or a single nodule. The cluster is usually centered in a horizontal plane which is slightly lateral to the greatest convexity of the anterior surface of the talus and the ossification center of the medial cuneiform.

Standard Plates 12 and 13



II

Lateral view. Localized shaping of the silhouette begins with flattening of its posterior (talar) surface. The longest axis of the nodule is vertical.

Dorsoplantar view. The longest axis of the nodule is transverse. The flattening of the posterior surface is visible in this view.

Standard Plates 12 and *13*

III

Lateral view. The posterior margin is becoming thickened centrally, and it is distinctly flattened.

Dorsoplantar view. The circumference of the silhouette shows the following subdivisions; its flattened navicular facet (lower arrow), its small rounded cuboid facet, and its flattened lateral cuneiform facet (upper arrow).

Standard Plates 14 and 15

IV

Lateral view. The posterior (talar) surface is slightly indented and thickened.

Dorsoplantar view. The facet which articulates with the medial cuneiform has become flattened.

Standard Plates 16 and 17

V

Lateral view. Its posterior surface has become distinctly concave.

Dorsoplantar view. The portion of the surface which faces the intermediate cuneiform has begun to flatten. The arrow points to an etched marking which is the forerunner of a distinct arc within the shadow. This marking designates onset of ossification of the osseous corner at the intersection of the plantar, medial, and posterior surfaces.

Standard Plates 17 and 18

Maturity Indicators of the Navicular

Views:

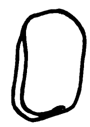
Lateral | Dorsoplantar

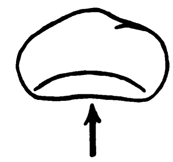
VI

Lateral view. The silhouette has become squarish. Osseous corners demarcate its circumference into four parts; posterior (talar), upper (dorsal or free), lower (plantar or free), and distal (cuneiform) margins.

Dorsoplantar view. Within the bone shadow, a distinct arc is forming—the outline of its talar facet.

Standard Plates 20 and 21





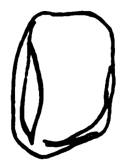
VII

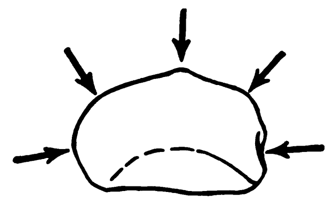
Lateral view. The outline of its medial surface has begun to project backward across the outline of its talar facet.

Dorsoplantar view. Beginning with the lowest left-hand arrow and proceeding clock-wise, successive pairs of arrows mark off the extent of its cuneiform facets as follows: the lateral cuneiform, the intermediate cuneiform, and the medial cuneiform (facet).

The lowest right-hand arrow designates the position of the tubercle of the navicular, which is the latest of its processes to begin to ossify.

Standard Plates 24 and 25





VIII

Lateral view. The outline of the plantar ridge projects below the major portion of the silhouette.

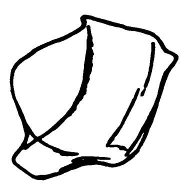
Dorsoplantar view. The posterior (talar) surface of the bone caps the talus throughout its extent.

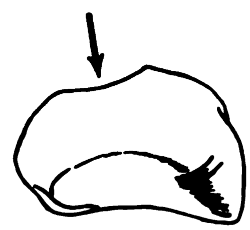
Each facet is marked off distinctly by osseous corners.

The intermediate cuneiform facet has become wide and concave.

If an accessory ossicle develops in lieu of the tuberosity of the navicular, it completes the medial portion of the talar articular arc.

Standard Plates 26 and 27

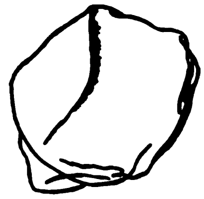


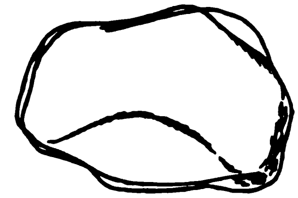


IX

Young adult contours.

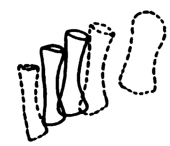
Standard Plates 28 and 29





Sketches of the four lateral metatarsals have been used interchangeably to illustrate successive maturity indicators.

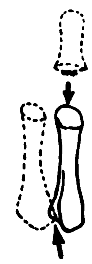
View:
Dorsoplantar



I

Each shaft is tubular and slightly constricted across the center. Each metaphysis is flattened. The base of each metatarsal (its proximal end) is slightly flared and the margins are smooth.
The four epiphyses, in the distal ends of the shafts, are entirely cartilaginous.

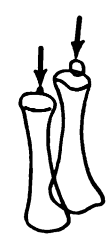
	Second	Third
Standard Plates	*1* and 2	*1* and 2
	Fourth	Fifth
Standard Plates	*1* and 2	*1* and 2



II

The distal one-half of each shaft has become relatively slender. The cortex has begun to appear thickened centrally; modeling of the shaft is thus beginning.
The base of the second metatarsal usually presents an angular outline. The bases of the third, fourth, and fifth metatarsals have obtuse marginal outlines or one side of the base is becoming beveled. The base of the fifth metatarsal has begun to show a small beveled margin medially, the forerunner facet of its tarsometatarsal joint surface.

	Second	Third
Standard Plates	3 and 4	*4* and *5*
	Fourth	Fifth
Standard Plates	*4* and *5*	6 and 7



III

Ossification of the epiphysis begins with a single nodule, or, occasionally, several nodules. The ossification center soon becomes round or oval.
Each bone growth center is quite close to the metaphysis and the particles may appear superimposed upon it in the film.

	Second	Third
Standard Plates	*11* and 12	11 and 12
	Fourth	Fifth
Standard Plates	*12* and 13	*13* and 14

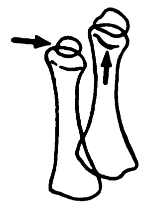
Maturity Indicators of the Second, Third, Fourth, and Fifth Metatarsals

View:
Dorsoplantar

IV

The longest axis of the epiphysis is transverse. The inner bone margin of each epiphyseal nodule begins to conform to the shape of the metaphysis.

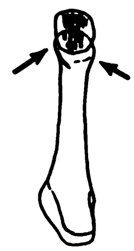
	Second	Third
Standard Plates	*12* and 13	12 and *13*
	Fourth	Fifth
Standard Plates	*13* and 14	14 and 15



V

The characteristic thickness of each growth cartilage plate has been established centrally.
The outer bone margin of each epiphysis has begun to appear flattened.

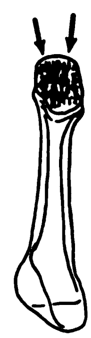
	Second	Third
Standard Plates	14 and 15	14 and *15*
	Fourth	Fifth
Standard Plates	15 and *16*	*16* and 17



VI

The inner bone margin of the epiphysis has become as wide as the metaphysis. The extent of the plantar ridge is indicated by the dense trabecular pattern within the epiphyseal shadow.
Osseous corners are forming at the junctions of the epiphyseal articular facet and the sides.
Similarly, on the base of each metatarsal, osseous corners are forming at the junctions of its articular facet and its sides.

	Second	Third
Standard Plates	23 and 24	23 and 24
	Fourth	Fifth
Standard Plates	23 and *24*	23 and *24*

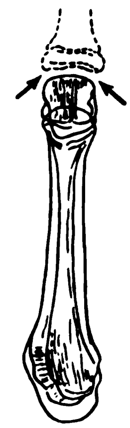


View:
Dorsoplantar

VII

The thickness of each growth cartilage plate is uniform across the entire shaft.
The span of the epiphyseal articular facet and the span of the diaphyseal growth cartilage plate are equal.
The articular facets on the bases are individualized in slope, distinctly outlined, and demarcated from the sides by blunted osseous corners.
The epiphysis of each metatarsal is capped by the phalangeal epiphysis.

	Second	Third
Standard Plates	24 and 25	24 and 25
	Fourth	Fifth
Standard Plates	24 and 25	24 and 25



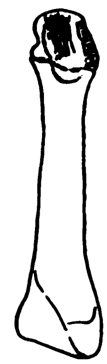
VIII

The strip of lesser density has been reduced to a very thin outline, and the growth cartilage plate appears uniformly hazy. Epiphyseal-diaphyseal fusion is beginning. However, the terminal plate and metaphysis can each be traced across each shaft.

	Second	Third
Standard Plates	26 and 27	26 and 27
	Fourth	Fifth
Standard Plates	26 and 27	26 and 27

Maturity Indicators of the Second, Third, Fourth, and Fifth Metatarsals

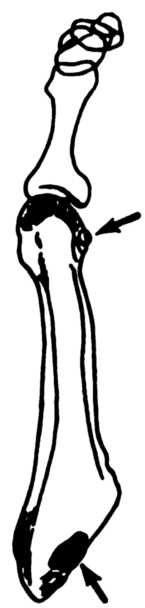
View:
Dorsoplantar



IX

Epiphyseal-diaphyseal fusion has recently been completed. The terminal plate and the metaphysis cannot be identified as separate outlines. The terminal line is thin and indistinct.

	Second	Third
Standard Plates	27 and 28	27 and 28
	Fourth	Fifth
Standard Plates	27 and 28	27 and 28



X

A film of the fifth toe was used to illustrate this stage of development.
The terminal plate and growth cartilage plate are no longer visible. Terminal lines may remain visible throughout life.
The upper arrow points to the sesamoid bone in this child's foot. Sesamoids characteristically form in the same plane as the growth cartilage plate.
The lower arrow points to the small area of increased density which marks the site of attachment of the peroneus brevis muscle. Here, radiographically, this marking is superimposed upon the articular facet in the base of the fifth metatarsal, the most lateral articulation of the tarsometatarsal joints.

	Second	Third
Standard Plates	30 and 31	30 and 31
	Fourth	Fifth
Standard Plates	30 and 31	30 and 31

Maturity Indicators of the Proximal Phalanges of the Second, Third, Fourth and Fifth Toes

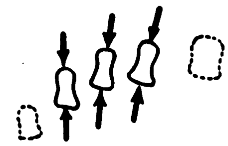
Sketches of the proximal phalanges of the four lateral toes have been used interchangeably to illustrate successive maturity indicators for all four of these phalanges.

I

The distal ends of the diaphyses are rounded and their proximal ends, the metaphyses, are flat. The shafts, especially those of the second, third, and fourth phalanges, are somewhat constricted across the center. Each epiphysis is entirely cartilaginous.

	Second	Third
Standard Plates	*1* and 2	*1* and 2
	Fourth	**Fifth**
Standard Plates	*1* and 2	*1* and 2

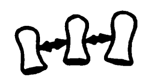
View:
Dorsoplantar



II

The metaphyses are smooth and thickened. Centrally, the sides of the diaphyses are distinctly thickened. Modeling of each shaft is established.

	Second	Third
Standard Plates	1 and 2	1 and 2
	Fourth	**Fifth**
Standard Plates	1 and 2	1 and 2



III

Ossification of the epiphysis begins with a single nodule or with multiple tiny nodules. The first deposit is close to the center of the future osseous articular surface.

	Second	Third
Standard Plates	*9* and 10	7 and *8*
	Fourth	**Fifth**
Standard Plates	*8* and 9	9 and *10*

Maturity Indicators of the Proximal Phalanges of the Second, Third, Fourth and Fifth Toes

IV

If ossification of the epiphysis begins with a single nodule, it now becomes disk-shaped; or the separate particles become arrayed transversely. The longest axis of the epiphysis is quickly established as its transverse axis before the nodule becomes half as wide as the metaphysis.

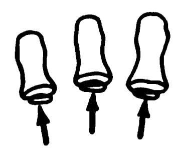
View:
Dorsoplantar

	Second	Third
Standard Plates	9 and 10	*9* and 10

	Fourth	Fifth
Standard Plates	9 and 10	9 and *10*

V

The central portion of the growth cartilage plate has attained its definitive thickness. The epiphysis has become half as wide the metaphysis.
Distally, the future articular margin of the shaft has begun to flatten.

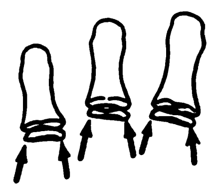


	Second	Third
Standard Plates	10 and 11	10 and 11

	Fourth	Fifth
Standard Plates	10 and 11	12 and 13

VI

The articular facet of the epiphysis has become flattened and thickened; each facet has become as wide as the (adjacent) epiphyseal facet of the metatarsal with which it forms a joint.



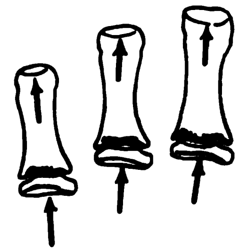
	Second	Third
Standard Plates	*16* and 17	16 and *17*

	Fourth	Fifth
Standard Plates	16 and *17*	*17* and 18

Maturity Indicators of the Proximal Phalanges of the Second, Third, Fourth and Fifth Toes

VII

View:
Dorsoplantar



Each epiphyseal facet has become concave and as wide as the corresponding metaphysis.
The sides of the epiphysis are beginning to appear thickened; this thickening usually begins on the medial side.
The non-epiphyseal (distal) end of each phalanx has lost its rounded appearance, and its center is slightly concave. The trochlear articular facet is forming there.

	Second	Third
Standard Plates	23 and 24	23 and 24
	Fourth	**Fifth**
Standard Plates	24 and 25	24 and 25

VIII

Sharp osseous corners are forming at the junctions of the inner bone margin of the epiphysis and the epiphyseal sides; the epiphysis has begun to cap the metaphysis.
The distal articular facet of each phalanx has become distinctly concave throughout its extent.

	Second	Third
Standard Plates	24 and 25	24 and 25
	Fourth	**Fifth**
Standard Plates	24 and 25	25 and 26

IX

The strip of lesser density can no longer be traced; the growth cartilage plate has been replaced with bone. The terminal line remains thick and distinct.
The articular facet at the distal end of each phalanx is marked off from the sides of the diaphysis by blunted osseous corners.

	Second	Third
Standard Plates	26 and 27	26 and 27
	Fourth	**Fifth**
Standard Plates	26 and 27	27 and 28

Maturity Indicators of the Proximal Phalanges of the Second, Third, Fourth and Fifth Toes

View:
Dorsoplantar

X

Epiphyseal-diaphyseal fusion has been completed. The terminal line usually disappears, but thin portions of it may remain visible throughout life.

	Second	Third
Standard Plates	*28* and 29	*28* and 29
	Fourth	Fifth
Standard Plates	28 and 29	*29* and 30

Maturity Indicators of the Metatarsal, Proximal Phalanx, and Distal Phalanx of the Great Toe

View:
Dorsoplantar

I

Metatarsal. The distal margin of the diaphysis is convex. The proximal margin, the metaphysis, is comparatively flat.

Proximal phalanx. The distal end of the shaft is dome-shaped. Its proximal margin, the metaphysis, is quite flat.

Distal phalanx. Its silhouette is usually triangular. Its proximal margin, the metaphysis, is flattened.

Epiphyses. The three epiphyses are as yet entirely cartilaginous.

	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	*1* and 2	*1* and 2	*1* and 2

II

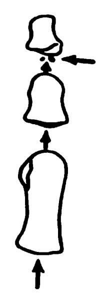
Metatarsal. On the lateral side of the distal end, a small tuberous process and a flattened outline have become visible. The shaft has grown proportionately longer. Proximal to the tuberous process and the outline, mid-shaft modeling has been established.

Proximal phalanx. Mid-shaft modeling has begun.

Distal phalanx. Mid-shaft modeling has begun. Accordingly, the bone appears flared at each end.

	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	*5* and *6*	*5* and *6*	*5* and *6*

III



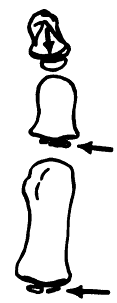
Epiphyses. Ossification of the epiphyses usually begins in the distal phalanx. The initial particles usually appear close to the metaphysis. The longest axis of the epiphysis is immediately shown by the transverse array of the initial particles.

	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	*9* and 10	*9* and 10	*8* and 9

Maturity Indicators of the Metatarsal, Proximal Phalanx, and Distal Phalanx of the Great Toe

IV

View:
Dorsoplantar



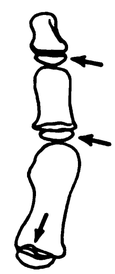
Metatarsal. Epiphyseal ossification begins close to the straight outline of the silhouette of the metaphysis. The longest initial axis of the epiphysis is indicated by the transverse array of the osseous nodules.

Proximal phalanx. Epiphyseal ossification begins close to the center of the metaphysis. Its longest axis is transverse.

Distal phalanx. The epiphysis appears thickened centrally. The thickening occurs before the nodule is half as wide as the metaphysis.

	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	9 and 10	9 and 10	9 and 10

V



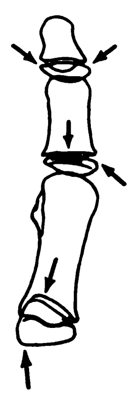
Metatarsal. The *lateral* portion of the epiphysis has become thickened.

Proximal phalanx. The *medial* side of the epiphysis is relatively thick, its lateral side is pointed.

Distal phalanx. The *central* portion of the epiphysis is distinctly thickened, its medial side is blunted, and its lateral side is pointed.

	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	*12* and 13	12 and 13	12 and 13

VI



Metatarsal. The silhouette of the epiphysis has become distinctly triangular. The arrows point to its beveled lateral side.

Proximal phalanx. The epiphysis is as wide as the metaphysis. It is also as wide as the adjacent (the distal) articular margin of the metatarsal, with which it forms a joint.

Distal phalanx. The articular facet has become as wide as the corresponding metaphysis. The thickest portion of the epiphysis is slightly eccentric, and is closest to the medial side of the shaft.

	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	18 and 19	21 and 22	18 and *19*

Maturity Indicators of the Metatarsal, Proximal Phalanx, and Distal Phalanx of the Great Toe

View:
Dorsoplantar

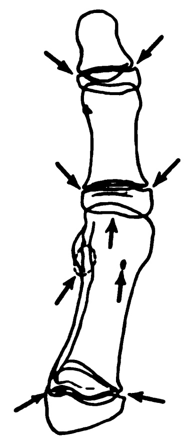
VII

Metatarsal. The entire strip of lesser density is uniform; the characteristic thickness of the growth cartilage plate is thus indicated.

Proximal phalanx. The lateral side of the epiphysis has become flattened and beveled. The epiphysis has begun to cap the metaphysis medially. The distal (non-epiphyseal) articular facet of the phalanx is concave, and its extent is marked off by blunted osseous corners.

Distal phalanx. The epiphysis has begun to cap the metaphysis medially.

Sesamoids. Ossification of the sesamoids has begun. The initial nodules became visible either within the shadow of the metatarsal or close to the tuberous process on its distal end.



	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	*24* and *25*	*24* and *25*	*24* and *25*

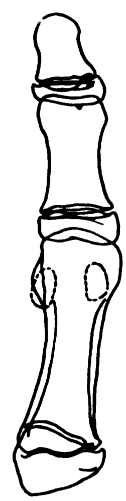
	Sesamoids
Standard Plates	24 and 25

VIII

Metatarsal. The full extent of the articular facet is established.

Proximal phalanx. The epiphysis caps the metaphysis and the distal end of the metatarsal as well.

Distal phalanx. The strip of lesser density is very narrow and has become hazy centrally. Epiphyseal-diaphyseal fusion is beginning.



	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	*25* and *26*	*25* and *26*	*25* and *26*

Maturity Indicators of the Metatarsal, Proximal Phalanx, and Distal Phalanx of the Great Toe

View:
Dorsoplantar

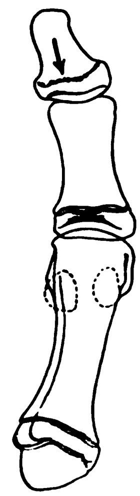
IX

Metatarsal. Although the outlines of the inner bone margin and the metaphysis can be traced, the strip of lesser density has become narrow and hazy. Epiphyseal-diaphyseal fusion is in process.

Proximal phalanx. Epiphyseal-diaphyseal fusion is well advanced. The outlines of the metaphysis and the terminal plate can be traced.

Distal phalanx. The terminal line is thickest centrally. The strip of lesser density can no longer be traced; presumably the growth cartilage plate has been eliminated from the bone.

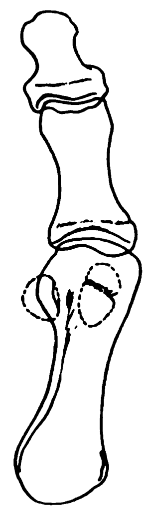
	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	26 and 27	26 and 27	26 and 27



X

Epiphyseal-diaphyseal fusion has been completed throughout the toe. The terminal lines may remain visible throughout life.

	Metatarsal	Proximal Phalanx	Distal Phalanx
Standard Plates	28 and 29	28 and 29	28 and 29



APPENDIX

TABLE X
Onset of Ossification

Bone Growth Center in:	*Fels Research Institute Boys:*				*Brush Foundation Boys:*				
	No. of Boys	*Mean (Months)*	*S.D.*	*No. of Boys*	*Mean (Months)*	*S.D.*	*No. of Boys*	*Mean (Months)*	*S.D.*
Femur, Head	50	4.4	2.0	100	4.5	1.8	182	4.7	1.8
Tibia, Distal epiphysis	50	3.9	1.5	100	4.3	1.8	186	4.4	1.6
Humerus, Capitulum	50	6.3	4.3	100	7.1	4.4	190	6.9	3.9
Humerus, Greater tubercle	50	11.4	7.2	100	12.3	7.0	187	12.4	6.7
Fibula, Distal epiphysis	50	12.5	4.1	100	12.1	4.2	193	12.6	4.2
Radius, Distal epiphysis	50	13.0	4.7	100	12.8	5.1	193	13.2	5.4
Finger 3, Pros. phal. epiph.	50	16.2	5.3	100	15.5	4.0	192	15.0	4.2
Toe I, Distal phal. epiph.	50	16.8	5.6	100	15.9	5.8	183	15.5	5.1
Finger 2, Prox. phal. epiph.	50	17.3	5.0	100	16.5	4.3	186	16.1	4.3
Finger 4, Prox. phal. epiph.	50	17.7	5.4	100	17.2	4.8	187	16.6	4.9
Metacarpal 2, Epiphysis	50	17.9	5.7	100	18.1	5.5	198	18.0	5.1
Finger 1, Distal phal. epiph.	50	18.4	6.2	100	18.6	6.8	191	18.3	6.3
Toe III, Prox. phal. epiph.	50	19.5	5.2	100	18.6	4.7	187	18.1	4.8
Metacarpal 3, Epiphysis	50	21.1	6.4	100	20.4	5.2	196	20.5	5.4
Toe IV, Prox. phal. epiph.	50	21.0	5.1	100	20.3	5.1	182	20.0	5.0
Toe II, Prox. phal. epiph.	50	22.2	5.8	100	20.9	5.2	187	20.7	5.1
Finger 5, Prox. phal. epiph.	50	22.2	5.6	100	21.4	5.3	193	21.5	5.3
Medial cuneiform	50	21.9	9.9	100	24.7	10.5	197	24.1	10.4
Metacarpal 4, Epiphysis	50	23.6	7.1	100	23.0	6.3	194	23.3	6.2
Finger 3, Middle phal. epiph.	50	24.9	7.6	100	23.8	6.0	194	23.4	6.3
Finger 4, Middle phal. epiph.	50	24.9	7.8	100	24.2	5.9	193	23.8	6.1
Metacarpal 5, Epiphysis	50	26.0	8.0	100	25.7	7.3	197	26.0	7.0
Finger 2, Middle phal. epiph.	50	26.9	7.5	100	25.8	6.4	191	25.8	6.6
Triquetral	50	27.3	15.9	100	29.6	16.3	220	29.3	16.4
Intermediate cuneiform	50	28.4	11.2	100	28.8	8.7	208	29.3	9.0
Toe I, Prox. phal. epiph.	50	29.9	5.8	100	27.8	5.4	203	27.7	5.3
Finger 3, Distal phal. epiph.	50	27.8	6.4	100	27.6	6.2	200	27.4	6.4
Finger 4, Distal phal. epiph.	50	28.3	7.0	100	27.9	6.5	199	27.7	6.5
Metatarsal 1, Epiphysis	50	27.7	4.7	100	28.7	4.9	206	28.5	4.9
Navicular (foot)	50	33.4	13.5	100	30.7	13.5	213	33.8	13.9
Toe V, Prox. phal. epiph.	50	32.0	5.9	100	31.0	7.0	203	30.5	6.4
Metacarpal 1, Epiphysis	50	29.8	7.3	100	31.6	8.7	207	31.8	8.4
Finger 1, Prox. phal. epiph.	50	34.8	7.9	100	32.4	7.5	208	33.2	7.7
Metatarsal 2, Epiphysis	50	33.4	6.8	100	34.2	6.9	214	35.3	6.8
Finger 5, Distal phal. epiph.	48	37.4	7.4	100	37.2	8.9	212	37.3	8.5
Finger 2, Distal phal. epiph.	48	37.0	7.9	100	37.3	7.9	209	37.6	7.9
Finger 5, Middle phal. epiph.	48	40.3	11.7	100	39.0	9.8	217	39.2	10.3
Metatarsal 3, Epiphysis	47	41.5	7.9	100	41.2	8.0	216	42.1	7.7
Lunate	48	46.0	19.3	100	42.4	19.0	227	44.4	18.9
Femur, Greater trochanter	48	42.6	7.6	100	42.1	9.8	220	41.9	8.6
Fibula, Proximal epiphysis	46	47.0	11.8	100	45.2	12.1	225	47.0	12.5
Patella	36	51.9	11.6	100	46.0	11.4	231	47.7	11.8
Metatarsal 4, Epiphysis	46	48.7	9.0	100	46.9	7.9	229	47.8	7.7
Toe IV, Distal phal. epiph.	44	51.2	10.1	100	50.9	12.8	223	52.2	11.6
Metatarsal 5, Epiphysis	45	53.6	10.6	100	53.0	9.9	237	53.6	9.2
Toe III, Distal phal. epiph.	44	53.5	11.2	100	53.2	14.0	227	53.7	12.4
Toe II, Distal phal. epiph.	41	57.0	11.4	100	57.9	13.3	228	58.5	11.9
Scaphoid	38	60.1	14.1	100	66.0	15.2	236	67.8	15.3
Trapezium	39	64.3	19.7	100	67.0	19.2	238	68.4	18.6
Radius, Proximal epiphysis	37	63.5	17.2	100	65.3	14.8	230	66.0	16.1
Trapezoid	37	63.5	15.2	100	68.7	15.5	231	69.1	13.8
Humerus, medial epicondyle	37	73.6	17.5	100	72.7	14.9	224	75.6	15.3
Ulna, Distal epiphysis	31	82.4	10.6	100	82.5	14.0	228	82.4	14.2
Calcaneus, Epiphysis	31	89.6	14.0	100	88.6	11.5	235	90.3	12.6
Pisiform				100	120.4	12.1			
Adductor sesamoid (thumb)				100	152.7	12.1			
Flexor sesamoid (thumb)				100	156.2	12.2			
Os trigonum				100	132.1	23.0			
Os Vesalianum				100	144.1	12.3			

TABLE XI
ONSET OF OSSIFICATION

	Fels Research Institute Girls:				*Brush Foundation Girls:*				
Bone Growth Center in:	*No. of Girls*	*Mean (Months)*	*S.D.*	*No. of Girls*	*Mean (Months)*	*S.D.*	*No. of Girls*	*Mean (Months)*	*S.D.*
Femur, Head	50	3.7	1.6	100	3.6	1.6	149	3.9	1.9
Tibia, Distal epiphysis	50	3.4	1.4	100	3.7	1.4	153	4.0	1.5
Humerus, Capitulum	50	4.1	3.6	100	4.4	2.5	160	4.8	2.8
Humerus, Greater tubercle	50	6.6	3.3	100	6.5	2.9	155	6.7	3.1
Fibula, Distal epiphysis	50	9.3	2.6	100	8.7	2.8	165	9.0	2.8
Toe I, Distal phal. epiph.	50	10.6	2.8	100	9.4	3.0	167	9.4	3.0
Radius, Distal epiphysis	50	10.8	4.4	100	9.5	4.2	166	9.8	4.1
Finger 3, Prox. phal. epiph.	50	10.4	3.1	100	9.8	2.9	171	10.0	3.1
Finger 2, Prox. phal. epiph.	50	11.0	3.0	100	10.6	3.1	169	10.8	3.2
Finger 4, Prox. phal. epiph.	50	11.1	3.2	100	10.7	3.3	170	10.8	3.4
Toe 3, Prox. phal. epiph.	50	12.2	3.8	100	11.2	3.6	174	11.5	3.8
Finger 1, Distal phal. epiph.	50	12.8	5.0	100	11.6	4.2	171	12.1	4.6
Metacarpal 2, Epiphysis	50	12.8	3.7	100	12.0	3.2	174	12.3	2.9
Toe IV, Prox. phal. epiph.	50	13.6	3.8	100	12.4	3.8	173	12.7	4.1
Toe II, Prox. phal. epiph.	50	14.1	3.8	100	13.2	3.6	170	13.6	4.0
Metacarpal 3, Epiphysis	50	14.2	4.0	100	13.4	3.4	175	13.8	3.7
Finger 5, Prox. phal. epiph.	50	15.2	4.2	100	14.0	3.8	171	14.3	4.0
Finger 3, Middle phal. epiph.	50	15.9	4.9	100	14.7	4.6	171	15.4	5.5
Finger 4, Middle phal. epiph.	50	15.8	4.8	100	14.9	4.7	172	15.6	5.6
Metacarpal 4, Epiphysis	50	16.0	4.1	100	15.1	4.0	175	15.6	4.1
Medial cuneiform	50	16.7	8.5	100	15.6	6.8	174	15.7	6.9
Finger 2, Middle phal. epiph.	50	17.3	5.2	100	16.4	4.6	171	17.2	5.6
Metacarpal 5, Epiphysis	50	17.2	4.7	100	16.5	4.7	174	17.1	4.8
Finger 3, Distal phal. epiph.	50	20.2	3.9	100	17.6	4.5	179	18.4	5.2
Toe I, Prox. phal. epiph.	50	20.3	5.5	100	18.1	4.2	170	18.8	4.8
Metacarpal 1, Epiphysis	50	20.3	5.3	100	18.1	4.7	176	19.1	5.1
Finger 4, Distal phal. epiph.	50	19.9	5.9	100	17.8	4.8	179	18.7	5.4
Metatarsal 1, Epiphysis	50	20.1	3.3	100	19.2	3.4	179	19.9	3.9
Intermediate cuneiform	50	21.3	7.6	100	19.1	6.6	181	20.0	6.7
Finger 1, Prox. phal. epiph.	50	21.6	5.1	100	20.0	5.1	169	20.9	5.6
Toe V, Prox. phal. epiph.	50	21.3	4.8	100	20.1	5.4	173	20.9	5.8
Finger 5, Middle phal. epiph.	50	24.9	7.9	100	22.1	7.5	190	23.6	8.4
Triquetral	50	23.6	13.7	100	21.0	13.7	182	22.7	13.4
Finger 5, Distal phal. epiph.	50	25.5	7.0	100	22.8	5.8	186	23.7	6.3
Navicular (foot)	50	25.8	11.1	100	21.4	9.8	177	23.3	10.9
Finger 2, Distal phal. epiph.	50	25.8	6.9	100	23.4	5.8	185	24.1	6.5
Metatarsal 2, Epiphysis	50	25.8	6.1	100	24.0	4.7	186	24.3	5.0
Femur, Greater trochanter	50	29.8	6.4	100	29.0	5.2	189	28.4	5.4
Metatarsal 3, Epiphysis	50	29.1	6.4	100	28.6	5.6	200	28.6	5.6
Toe IV, Distal phal. epiph.	50	30.7	7.9	100	28.9	6.9	199	30.3	7.6
Patella	43	34.8	8.5	100	29.1	7.3	196	30.3	7.6
Toe III, Distal phal. epiph.	50	32.8	7.7	100	32.8	8.2	199	34.0	8.8
Metatarsal 4, Epiphysis	50	34.0	7.2	100	33.2	7.2	211	33.4	7.1
Fibula, Proximal epiphysis	50	32.6	9.3	100	33.0	11.2	194	34.3	10.6
Lunate	50	34.6	14.2	100	34.3	13.5	195	36.0	13.4
Toe II, Distal epiphysis	50	35.5	7.3	100	35.1	8.4	198	36.2	9.1
Metatarsal 5, Epiphysis	50	38.6	8.4	100	38.5	8.5	218	38.9	8.6
Humerus, Medial epicondyle	48	41.3	9.9	100	43.2	12.2	218	43.0	11.9
Radius, Proximal epiphysis	46	47.5	12.1	100	48.7	13.9	226	50.3	14.6
Trapezium	46	47.0	14.8	100	47.3	14.2	229	47.4	14.6
Trapezoid	44	48.3	14.8	100	49.2	11.6	229	49.4	12.7
Scaphoid	45	47.8	12.3	100	50.9	11.8	228	50.4	12.6
Calcaneus, Epiphysis	42	63.7	11.8	100	60.0	10.6	236	61.6	12.7
Ulna, Distal epiphysis	42	63.2	15.3	100	69.4	13.0	238	68.3	13.1
Pisiform				100	94.6	13.1			
Adductor sesamoid (thumb)				100	123.4	11.0			
Flexor sesamoid (thumb)				100	132.0	12.0			
Os trigonum				100	97.1	12.3			
Os Vesalianum				100	116.7	12.1			